

DRAFT FINAL MSGRP REMEDIAL INVESTIGATION REPORT

**Industri-Plex Superfund Site
Operable Unit 2
Woburn, Massachusetts**

March 2005

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**DRAFT FINAL
MSGRP REMEDIAL INVESTIGATION REPORT**

**VOLUME 1 OF 12
TEXT, TABLES, AND FIGURES**

REMEDIAL INVESTIGATION/FEASIBILITY STUDY

**INDUSTRI-PLEX SITE
WOBURN, MASSACHUSETTS**

RESPONSE ACTION CONTRACT (RAC), REGION I

**For
U.S. Environmental Protection Agency**

**By
Tetra Tech NUS, Inc.**

**EPA Contract No. 68-W6-0045
EPA Work Assignment No. 116-RICO-0107
TtNUS Project No. GN4123**

March 2005



TETRA TECH NUS, INC.

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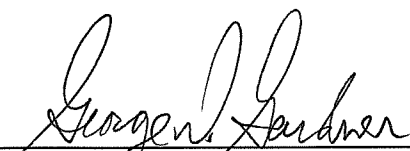
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ACRONYMS

21E	310 Code of Massachusetts Regulations (CMR) Chapter 21E
AST	above ground storage tank
As	arsenic
ATSDR	Agency for Toxic Substances and Disease Registry
AUL	Activity and Use Limitation
AVS	acid volatile sulfide
B&M	Boston and Maine
BECO ROW	Boston Edison Company Right of Way
BERA	baseline ecological risk assessment
BTEX	benzene, toluene, ethyl benzene, xylene
CBCA	Cranberry Bog Conservation Area
CD	Consent Decree
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Information System
cfs	cubic feet per second
COC	contaminant of concern
COD	chemical oxygen demand
COE	U.S. Army Corps of Engineers
COPC	contaminant of potential concern
CPAH	carcinogenic polynuclear aromatic hydrocarbons
Cr	chromium
CT	central tendency

CVOC	chlorinated volatile organic compounds
DCA	dichloroethane
DCE	dichloroethene
DDT	p,p'-Dichlorodiphenyltrichloroethane
DEP	Department of Environmental Protection
DEQE	Department of Environmental Quality Engineering
DNAPL	dense non-aqueous phase liquid
DNR	Department of Natural Resources
DO	dissolved oxygen
DOC	dissolved organic carbon
DPS	downgradient property status
DPT	direct push technology
DPW	Department of Public Works
EPA	United States Environmental Protection Agency
EPC	exposure point concentration
ERA	ecological risk assessment
Fe	iron
FS	Feasibility Study
gpd	gallons per day
g/hr	grams per hour
gpm	gallons per minute
GPR	ground penetrating radar
GSIP	Groundwater/Surface Water Investigation Plan
HBHA	Halls Brook Holding Area
Hg	mercury
HHRA	human health risk assessment

HI	hazard index
HQ	hazard quotient
I-95	Interstate 95
I-93	Interstate 93
ISRT	Industri-Plex Site Remedial Trust
IRA	Immediate Response Action
IWPA	Interim Wellhead Protection Area
J	Estimated value based on data QC
lb	pound
LLC	limited liability corporation
LOAEL	lowest observed adverse effect level
LNAPL	Light Non-Aqueous Phase Liquid
MADEP	Massachusetts Department of Environmental Protection
MAPC	Metropolitan Area Planning Council
MBTA	Massachusetts Bay Transportation Authority
MCL	maximum contaminant limit
MCP	Massachusetts Contingency Plan
MDC	Metropolitan District Commission
M&E	Metcalf & Eddy, Inc
mgd	million gallons per day
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MIT	Massachusetts Institute of Technology
MPT	Mark Phillip Trust
MRA	Massachusetts Rifle Association
MSGRP	Multiple Source Groundwater Response Plan

MSMA	Monosodium Methane Arsenate
MWRA	Massachusetts Water Resources Authority
NA	Not analyzed
NAPL	Non-aqueous phase liquid
NAS	Natural Attenuation Study
NAWQC	National Ambient Water Quality Criteria
NCDC	National Climatic Data Center
NCP	National Contingency Plan
ND	Not detected
NDS	Not a Disposal Site
NERL	New England Regional Laboratory
NFA	no further action
NOAA	National Oceanic Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPDWSA	Non-Potential Drinking Water Source Area
NPL	National Priorities List
NGVD	National Geodetic Vertical Datum
NWS	National Weather Service
OMEE	Ontario Ministry of the Environment and Energy
ORP	oxidation-reduction potential
OU	Operable Unit
ppm	part per million
PA	Preliminary Assessment
PAH	polynuclear aromatic hydrocarbons
Pb	lead
PCB	polychlorinated biphenyl compounds

PCE	tetrachloroethene
PID	photo-ionization detector
PPA	Prospective Purchaser Agreement
ppb	part per billion
ppm	part per million
PRG	Preliminary Remediation Goal
PRP	Potentially Responsible Parties
RAO	response action outcome
RAM	Release Abatement Measure
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
RCRA	Resource Conservation and Recovery Act
RME	reasonable maximum exposure
ROD	Record of Decision
RTC	(Anderson) Regional Transportation Center
RTN	Release Tracking Number
SARA	Superfund Amendments and Reauthorization Act
SEL	severe effects level
SEM	selective extractable metals
SIC	Standard Industrial Code
SP	Settling Parties
SVE	soil vapor extraction
SVOC	semi-volatile organic compound
SWAP	Source Water Assessment Program
TCA	trichloroethane
TCE	trichloroethene / trichloroethylene

TCO	total combustible organics
TDS	total dissolved solids
TNT	trinitro-toluene
TOC	total organic carbon
TPH	total petroleum hydrocarbons
TRC	TRC Environmental Corporation
TRV	toxicity reference value
TRI	toxic release inventory
Trust	Mark Phillip Trust
TSP	trisodium phosphate
TSS	total suspended solids
TtNUS	Tetra Tech NUS, Inc.
UCL	Upper Confidence Limit
µg/kg	microgram per kilogram
µg/L	microgram per liter
USDA	United States Department of Agriculture
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
UST	underground storage tank
UV	ultraviolet
VOC	volatile organic compound

E.0 EXECUTIVE SUMMARY

This Multiple Source Groundwater Response Plan Remedial Investigation (MSGRP RI) report describes the investigations and data evaluation activities conducted to assess contamination in groundwater, surface water, sediment, and soil at the Industri-plex Superfund Site (Site) and surrounding area, and surface water and sediment in the Aberjona River (i.e. MSGRP RI Study Area).

The objectives of the MSGRP RI are as follows:

- Compile and evaluate available site data and obtain additional data as necessary, to characterize the study area and determine the source(s) and the nature and extent of contamination within impacted media (soil, groundwater, sediment, and surface water)
- Identify potential contaminant migration pathways and receptors
- Assess the fate and transport of contaminants associated with the Site within the MSGRP RI Study Area
- Evaluate the potential threats to human health and the environment in the MSGRP RI Study Area by performing risk assessments
- Present data for use in developing the feasibility study, including development and screening of remedial alternatives.

E.1 Site Background

The Industri-plex Superfund Site (Site) is a 245-acre industrial park located in the northeast corner of Woburn, Massachusetts near the intersection of two major highways, I-93 and I-95 (Figure ES-1). The Site is bordered by two major interstate highways and by commercial and light industrial properties. The Aberjona River flows through a portion of the Site. Several associated tributaries, drainways, and wetlands also traverse or are situated on the Site. The nearest residences are located approximately 4,000 feet to the north, approximately 1,000 feet to the east, approximately 2,500 feet to the west, and approximately 4,000 feet to the south of the Site. According to EPA, approximately 34,000 people live within 3 miles of the Site. The Site is currently occupied by numerous active retail, commercial, and light industrial businesses as well as the Anderson Regional Transportation Center, a 33-acre commuter transportation hub, which was constructed on the Site in the late 1990s and opened in May 2001.

From 1853 through 1931, the Site was home to various chemical manufacturing operations that principally produced chemicals for the local textile, leather and paper industries; the main products being sulfuric acid and related chemicals. Other chemicals produced at this facility included arsenic insecticides, acetic acid, dry colors, and organic chemicals including phenol, benzene, picric acid, toluene, and TNT. Beginning in 1935, the plant was dedicated to the manufacturing of glue from animal hides until mid-1969 when operations ceased and the site was vacated.

In December 1968, the Mark Phillip Trust (MPT) purchased approximately 149 acres of the property from Stauffer Chemical Company, while others purchased the remaining 35 acres. The MPT intended to develop the Stauffer land, along with land owned to the south and east, as an industrial park to be called "Industri-plex 128". From early 1970 to 1979, development activities involved filling and excavating portions of the property to facilitate the sale of various parcels. Excavations uncovered chemical and glue manufacturing wastes, including decaying animal hides. In addition to two existing waste stockpiles (i.e. East Central Hide Pile and South Hide Pile), some of these waste deposits were excavated and either trucked off site, buried on the southern Boston Edison Company (BECO) right-of-way, or stockpiled in two new waste piles (i.e. West and East Hide Piles).

The releases of metals and organic compounds at the Industri-plex Site have resulted in onsite soil contaminant levels that exceed those in background and offsite reference locations. The contaminants gradually dispersed into the surrounding environmental media and have resulted in the contamination of soil, groundwater, surface water, sediments, and biota.

The Site was listed on the Superfund Interim List of 115 Top Priority Hazardous Waste Sites in 1981 and on the Superfund National Priorities List in 1983. In 1986, EPA completed a Record of Decision (ROD) that selected a cleanup remedy for the Site that included soil, air, and interim groundwater remedies. The soil remedy consisted of capping arsenic/lead/chromium contaminated soils and hide piles; the air remedy included construction of an impermeable cap and a gas collection and treatment system at the East Hide Pile; and groundwater was to be remediated in the interim through the construction of a treatment system for benzene and toluene "hot spot" areas. Institutional controls were considered a crucial part of the soil remedy to maintain the integrity of the cap into the future.

The remedial investigation that originally supported the 1986 ROD focused on site-specific soil and groundwater “hot-spot” problems and did not attempt to identify other possible sources of either upgradient or cross-gradient groundwater contamination or impacts to surface water. To fully understand the site-specific and area-wide groundwater issues, the ROD and the Consent Decree assigned separate responsibilities to the Settling Defendants and the EPA to conduct two additional studies. The Settling Defendants were required to implement the ROD-prescribed Groundwater/Surface Water Investigation Plan (GSIP) to assess the groundwater, surface water, and sediment contamination on site. The GSIP study area focused on site related contaminants and included the Industri-plex Superfund Site and downstream areas to I-95 (Northern Study Area). The EPA was required to implement the Multiple Source Groundwater Response Plan (MSGRP) to evaluate area-wide contamination issues outside of the GSIP study area. The description of the selected interim-remedy for groundwater noted that the findings and conclusions of the MSGRP would be used to develop and implement a final remedy for on-site groundwater problems. These decisions would also be based in part on the findings of the GSIP investigations.

While the GSIP and MSGRP investigations were being conducted to assess contamination in and around the northern reaches of the Aberjona River, an investigation of the Wells G&H Superfund Site, located about 1 mile south of the Industri-plex Site, was being conducted, which included an EPA-led investigation of the surface water and sediment of the southern portion of the Aberjona River to the Mystic Lakes. In 2002, EPA combined the separate surface water and sediment investigations being performed at the two Superfund sites into one study to more efficiently evaluate contamination and risk issues for the entire Aberjona River and ultimately develop one remedial decision for the river, if necessary. As a result, the MSGRP RI Study Area for surface water and sediments was expanded to include the southern reaches of the Aberjona River from I-95-South, through the Wells G&H Site, to the Mystic Lakes (i.e. Southern Study Area). It is important to note that the groundwater investigations for the MSGRP RI are limited to the general area surrounding and including the Industri-plex Site. Groundwater in the vicinity of the Wells G&H Superfund Site is currently being investigated, and in some areas remediated, as part of the Wells G&H Superfund Site cleanup program under the auspices of the EPA and MADEP.

Consequently, this MSGRP RI report presents and evaluates data from over 4,800 samples collected and evaluated as part of the MSGRP RI investigation. Samples were collected from

various media including soil, groundwater, surface water, sediment, soil gas, and various biota (both plant and animal). These sampling efforts were part of the investigations initially conducted for separate studies at the two Woburn, Massachusetts Superfund sites as described below:

- Industri-plex Superfund Site -- GSIP: Focused the investigation on groundwater, surface water, sediments, and soil at the Industri-plex Site and surrounding area, south to Mishawum Road and I-95; conducted in three separate phases from 1990 to 2004.
- Wells G&H Superfund Site -- Operable Unit 3 (OU-3), Aberjona River Study: Focused the investigation on surface water and sediment within the Aberjona River and its associated wetlands from I-95 south to the Mystic Lakes; conducted from 1995 to 2004.
- Industri-plex Superfund Site -- MSGRP: Incorporates the findings of the GSIP, Wells G&H OU-3 Aberjona River Study, Preliminary MSGRP – Industri-plex Study Area (1997), Preliminary MSGRP – Aberjona River Study Area (2002), and focused the investigation on area-wide groundwater, surface water, sediments, and soil contamination including areas adjacent to the Industri-plex Site, south to Mishawum Road and I-95, and at specific locations along the Aberjona River south of I-95; conducted from 2000 to 2004. The MSGRP also considered other relevant studies along the Aberjona River by the Massachusetts Institute of Technology (MIT).

E.2 MSGRP RI Investigations

The investigations that focused on the Industri-plex Site study area and the combined Industri-plex/Aberjona River study area were conducted principally by Tetra Tech NUS, Inc. (TtNUS) on behalf of EPA. The EPA New England Regional Laboratory (EPA NERL) conducted some sediment and soil sampling to supplement the investigations performed by TtNUS. In addition, EPA sponsored two investigations to support the MSGRP: 1) a natural attenuation study by the EPA Office of Research and Development (EPA ORD) to investigate transport mechanisms for metals in groundwater and sediments at the Industri-plex Site; and 2) an arsenic bio-availability study by researchers at the University of Missouri, Columbia, and Syracuse Research Corporation, in Denver Colorado, to assess bio-uptake of arsenic from site sediments.

The initial investigation of the Wells G&H Aberjona River Study Area was conducted for EPA by Foster Wheeler (FW, formerly Ebasco) in 1995. This study then transitioned to Metcalf and Eddy (M&E), who conducted a follow up field investigation and data evaluation in 1997 to support the baseline risk assessments for the Wells G&H Site Aberjona River Study (OU-3).

The data collected during these investigations, combined with the data collected by the ISRT under the GSIP, and data collected during the initial 1983 site investigations are combined and evaluated in this comprehensive MSGRP RI.

E.2.1 MSGRP Study Area Description

The MSGRP RI Study Area is located within the Aberjona River Watershed. The Aberjona River is the primary river system in the Aberjona River basin and has an approximate 65-square kilometers (km²) drainage area. The river flows through Woburn and Winchester, Massachusetts terminating in Winchester where it discharges into the Mystic Lakes.

The most significant water bodies located in the northern part of the MSGRP RI Study Area include: Halls Brook, Halls Brook Holding Area (HBHA), and the Aberjona River. With the exception of Halls Brook, all of these water bodies were either modified or created for flood storage capacity during development of the area. Fed primarily by Halls Brook, the Halls Brook Holding Area (HBHA) was created as a storm water management area following the filling of Mishawum Lake. The northern portion of the HBHA consists of a large rectangular shallow pond (approximately 175 feet x 900 feet and depth up to 20 feet), referred to as the HBHA Pond. Downstream of the HBHA Pond, the southern portion of the HBHA consists of wetlands containing three smaller ponds. When the HBHA was constructed, the Aberjona River was diverted from Mishawum Lake to its current course which follows a series of culverts and drainage channels in the middle of Commerce Way roadway that parallels the HBHA approximately 1,500 feet to the east. Flows from the Aberjona River and the HBHA converge at the outlet of the HBHA at Mishawum Road.

The entire Southern Study Area (the Aberjona River and its floodplains) lies within the 100-year floodplain; wetland areas adjacent to the Aberjona River are scattered throughout the Southern Study Area. The most significant wetland areas include the Wells G&H wetland and the Cranberry Bog Conservation Area (CBCA) wetland. The low-lying areas along the river

frequently experience flooding due to increased storm water contributions from developed and paved areas, causing the Aberjona River to exceed its flow capacity. The most significant water bodies include the Upper and Lower Mystic Lakes where the Aberjona discharges.

The Aberjona River flows through urbanized sections of Woburn and Winchester. Both of these municipalities have an extensive industrial history, principally involving the tanning industry dating back into the early 1800s. Historically, waste products from these industries were reportedly discharged into the Aberjona River and may have contributed to the historical contamination of the river's water quality and sediments.

In 1986, a ROD was entered for the Industri-plex Site that required multiple remedial tasks and additional investigations including the investigation of Site-related contamination (metals, benzene and toluene) downstream in the surface water and sediments along the HBHA and Aberjona River to I-95 (referred to as the Northern Study Area or Reach 0); completion of an RI/FS to evaluate other potential groundwater contamination sources around the Site, incorporate the PRPs' Site-related investigation data into the RI/FS, and determine the need for additional action (i.e. final groundwater remedy, and surface water/ sediment cleanup, as necessary). This MSGRP RI report presents the findings of those investigations.

E.3 Summary of Findings

The MSGRP RI Study Area is divided into reaches based on similarity of habitat, species, and accessibility. This concept was first introduced during the preparation of the baseline ecological risk assessment for the Aberjona River Study (OU-3) whereby the Aberjona River was divided into six reaches (1 through 6). For purposes of continuity, the same reaches were used in the human health risk assessment for the Aberjona River Study. When EPA decided to merge the MSGRP RI and Aberjona River Study investigations, the original six reaches were expanded to include "Reach 0", which represents the entire Northern Study Area. The study area reaches are shown on Figure ES-2 and are generally described as follows:

MSGRP RI STUDY AREA		
NORTHERN STUDY AREA	Reach 0	Industri-plex Site, northern section of Aberjona River, and the HBHA Pond and Wetlands south to I-95.
SOUTHERN STUDY AREA	Reach 1	From I-95, south to Salem Street, including the Wells G&H wetlands
	Reach 2	Salem Street south to the river crossing at Washington Street in Winchester, including the Cranberry Bog Conservation Area
	Reach 3	Washington Street South to Swanton Street, including Davidson Park
	Reach 4	Swanton Street south to Mill Pond in Winchester center
	Reach 5	Mill Pond outlet south to Upper Mystic Lake inlet
	Reach 6	Upper Mystic Lake, including upper and lower forebays, and Lower Mystic Lake to the Mystic River.

The following sections describe the significant findings of the environmental investigations conducted as part of the MSGRP RI.

E.3.1 Significant Contaminant Sources

Heavy metals are the principal contaminant of concern throughout both the Northern and Southern Study area, with arsenic representing the most significant metal present at elevated concentrations throughout the system. The most significant source of metals contamination in both the Northern and Southern Study Areas has been from the Industri-plex Superfund Site. Historical releases include releases from surface water, sediment and soil since operations began in the 1850s until the protective remedial cap was implemented in the mid 1990s (the Aberjona River flowed through the middle of the Industri-plex Site until the 1970s when it was redirected along Commerce Way), as well as historical groundwater releases. Although the contaminated soils have been capped, they continue to impact Site groundwater which is discharging to the HBHA Pond, and Aberjona River. Once discharged to the surface water bodies, sediments are impacted and the contaminants continue transport further downstream as part of the suspended solid load or in the dissolved state through diffusion processes. Current releases include releases from groundwater, sediment and soil (total suspended solids) and sediment diffusion (dissolved arsenic).

Several organic contaminants were detected in soils and groundwater in the Northern Study Area. However, benzene was the most frequently detected VOC at concentrations exceeding

the MADEP GW-2 and GW-3 standards for groundwater. The highest concentrations of benzene were observed in the shallow groundwater in two areas of the site: between the East Central Hide Pile and the South Hide Piles; and within a localized area along the eastern edge of the West Hide Pile. High concentrations of benzene were observed in the deeper groundwater extending from the southern side of Atlantic Avenue to the central portion of the HBHA Pond. In general, the overall benzene plume, extending in both the shallow and deeper groundwater, is located in the vicinity of Atlantic Avenue south to the HBHA Pond. This current location is generally consistent with the findings of previous investigations conducted during the early GSIP investigations and the 1983 RI. These plumes were found to discharge into the HBHA Pond.

Other organic compounds, such as naphthalene and trichloroethene (TCE), were also observed sporadically in groundwater samples in the vicinity of the HBHA Pond. TCE was also observed in another area approximately 0.5 mile south of the Site, generally located south and southwest of Cabot Road, in the vicinity of former Mishawum Lake. However, based on the available groundwater data, it appears that the source of the TCE south of Cabot Road is not related to the Site.

E.3.2 Contaminant Migration

The fate and transport of contaminants evaluated in the MSGRP RI involve complicated and interdependent processes that affect mobilization of contaminants between various media and from reach to reach with the MSGRP RI Study Area. The principal source of contamination within the MSGRP Study Area is the soils underlying the Industri-plex Site. These contaminated soils are impacting groundwater, which in turn discharge to the HBHA Pond and wetlands and northern portions of the Aberjona River, subsequently impacting surface water. The surface water flows from the HBHA and Aberjona River combine at Mishawum Road and represents the primary contaminant transport vehicle for downgradient receptors. While the applicable fate and transport processes are generally the same throughout the Study Area, the impacted media and contaminants of concern vary from the northern portions of the Study Area to the lower portions of the Study Area and are summarized as follows:

ABERJONA RIVER SECTION	IMPACTED MEDIA	CONTAMINANTS OF CONCERN
Reach 0 (Industri-plex Site and the HBHA)	Soils, Groundwater, Sediment, Surface water	VOCs, SVOCs, Metals
Reach 1 (38-acre Wells G&H wetland)	Sediment, Surface water, Groundwater	Metals
Reach 2 to Reach 6 (Cranberry Bog Conservation Area to the Mystic Lakes)	Sediment, Surface water	Metals

The primary groundwater and surface water migration pathways were illustrated in Figure ES-3.

Leaching is the most significant ongoing transport process for metals in soils underlying the Industri-plex Site and impacting groundwater. Once in groundwater, contaminants continue to migrate via advection, diffusion, and dispersion processes. Significant contaminants found in groundwater include arsenic, benzene, toluene, and to a lesser degree lead and zinc. Once in the groundwater, contaminants are transported through groundwater flow paths and are predominantly discharged to the northern portions of the HBHA Pond, impacting sediments and surface water.

Constructed as a storm water management system during the early 1970s, the HBHA Pond is a large rectangular open surface water body at the northern end of the HBHA which receives groundwater discharges directly from the Industri-plex Site. The HBHA Pond is unique in that, due to the presence of a specific conductance chemo-cline induced by inputs of reduced groundwater originating from the Industri-plex Site and oxygenated surface water from Halls Brook, dissolved metals in groundwater are being partially sequestered in the HBHA Pond sediments. This chemocline also supports the biodegradation of benzene contaminants that are also being discharged by Site groundwater. As a result of the chemocline, high concentrations of dissolved arsenic, benzene and conductivity are detected in deeper portions of the pond's surface water, while very low concentrations are in the shallow surface water.

These processes however, are incomplete and some metals, primarily arsenic and iron, are being released into surface water as part of the suspended sediment load or in the dissolved state. These releases are occurring during both baseflow and storm flow conditions. During storm flow conditions however, the chemo-cline is disrupted and the amount of metals entering the water column and being transported further downstream is much greater. EPA studies have

shown that it may take as long as 1 month to restore the chemo-cline in the HBHA Pond after a significant storm event. Although surface water data have generally not identified metals exceeding National Ambient Water Quality Criteria (NAWQC) standards, except in deeper surface water at the HBHA Pond, the mass of metals represent a source of contamination to downstream depositional areas.

Although organic contaminants have been found to naturally attenuate in the water column either through dilution, biodegradation, or chemical degradation, heavy metals were found to migrate further downstream. Depending on the geochemical and flow conditions, dissolved metals in the water column may absorb to suspended solids, such as fine grained soil particles or other metal complexes and either precipitate and become part of the sediment bed load or be transported further downstream as part of the suspended solid load within the water column and be deposited at locations downstream. As part of the sediment bed load and depending on the geochemical conditions, metals may dissolve from the sediment particle back into the surface water, whereby the cycle of dissolution and precipitation would continue. This cycling was mostly observed within portions of the HBHA that exhibited significant anoxic/reduced conditions, specifically, within the HBHA Pond. However, whereas wetlands in general typically exhibit reduced conditions or present a significant source of sulfides under oxic conditions, this cycling may be occurring in other portions of the Study Area such as the Wells G&H wetlands.

The surface water investigation has shown that the metal concentrations are greater in the Northern Study Area (north of I-95) and progressively decrease as the river continues south to the Mystic Lakes, which is essentially the final depositional area for these metals. Arsenic was the most prevalent metal observed in surface water throughout the entire study area of the river. The most significant declines were observed between the HBHA outlet and the Wells G&H wetlands outlet indicating deposition of suspended solids to the sediment bed.

Sediment samples also follow a similar trend in that the highest concentrations of metals were detected in depositional areas in the northern reaches of the Aberjona River, specifically in the HBHA (Reach 0), the Wells G&H wetlands (Reach 1), and the Cranberry Bog Conservation Area (northern part of Reach 2). These data suggest that the metals originating from the Northern Study Area (i.e. HBHA Pond and wetlands) are being deposited in downstream wetland areas or quiescent sections of the river.

Due to concerns of metals possibly diffusing from contaminated sediments and potentially impacting groundwater, the RI investigations also evaluated the effect of the contamination in the river surface water and sediments on the potential drinking water supply in the Central Area aquifer of the Wells G&H Site. This investigation concluded that the weight of evidence does not indicate that dissolved arsenic present in the surface water and sediments will impact future potable supply wells within the Interim Wellhead Protection Area (e.g. Well G and Well H) above the current drinking water standard (10 ug/L).

E.3.3 Risk Assessments

The data collected during this investigation was evaluated for potential human health and ecological risks. Separate baseline risk assessments were completed for the Northern Study Area and the Southern Study Area. The results of these assessments have been evaluated, combined and refined into a comprehensive risk evaluation for the Industri-plex Site and the entire Aberjona River in Sections 6 and 7 of this comprehensive RI.

E.3.3.1 Summary of Human Health Risks

The potential non-carcinogenic hazards and carcinogenic risks were estimated for adults and/or children assumed to contact contaminants in surface water, sediment, sediment cores, fish tissue, soil, groundwater, and soil gas. Cumulative receptor risks and hazards, summed across all applicable media and pathways for each exposure area, were estimated and compared to the target cancer risk range and non-carcinogenic target hazard index established by EPA for the protection of human health. As identified in the baseline human health risk assessments and supported by EPA, the following contaminants, media, and locations exceed risk management guidelines established for human exposures (refer to Figure ES-4 for sediment and soil locations and Figure ES-5 for monitoring well locations):

Current Scenario

- Arsenic in sediment at Stations WH and CB-03 in the Southern Study Area.

Future Scenario

- Arsenic in sediment at Stations 13/TT-27, WH, NT-3, and CB-03 in the Southern Study Area;
- Arsenic at sediment core locations SC02 in the Northern Study Area and SC05, SC06, and SC08 in the Southern Study Area;
- Arsenic in soil at locations SO-3, SO-11, SO-13, SO-14, and SO-16 in the Northern Study Area;
- Arsenic in groundwater at monitoring wells B7-01, B4-04, B7-02, B6-03, B5-02, and B8-04 in the Northern Study Area;
- Benzene in groundwater at monitoring wells B5-01, W5-06, W5-05, B7-03, B9-02, B9-01, and W5-03 in the Northern Study Area;
- Trichloroethene in groundwater at monitoring wells AE-03, W5-03, AE-02, AE-04, and AE-06 in the Northern Study Area; and
- Naphthalene in groundwater at monitoring well W5-05 in the Northern Study Area.

It should also be noted that the migration of arsenic-contaminated surface water from the HBHA in the Northern Study Area to depositional areas in the Southern Study Area (i.e., the Wells G&H 38-acre wetland and the former cranberry bog) contribute to the human health risks and hazards above risk management guidelines observed at sediment stations 13/TT-27, WH, NT-3, and CB-03 in the Southern Study Area.

E.3.3.2 Summary of Ecological Risks

Comprehensive studies were conducted to estimate potential risks to ecological receptors throughout the study areas, exposed to contaminants in surface water, sediment, soil, and biota. Receptor populations or communities included representative mammals, birds, fish, and invertebrates. Based upon the evaluation conducted under this Baseline Ecological Risk

Assessment Summary for the combined study areas, and supported by EPA, significant ecological risks are present in the HBHA Pond within Reach 0 of the Northern Study Area immediately downstream of the current Industri-plex Superfund Site boundaries. These significant risks were primarily associated with metals contamination, particularly arsenic, in the sediment and their toxicological effects on the benthic invertebrate community (see Figure ES-4).

Risks to aquatic organisms are also associated with observed high concentrations of benzene and dissolved arsenic in the deep water of the HBHA Pond. Dissolved arsenic concentrations were measured significantly above National Ambient Water Quality Criteria values for aquatic life. These risks are consistent with the observed impairment of benthic invertebrates in the deep water of the HBHA Pond. These significant risks are considered unacceptable ecological risks to the HBHA Pond.

Risks to receptors downgradient of HBHA Pond are low. These include the low risks to benthic invertebrates and herbivorous mammals associated with high concentrations of arsenic in sediment. These low risks are not considered unacceptable ecological risks to ecological communities in the HBHA Wetlands, Wells G&H 38-acre wetland, and Former Cranberry Bog.

E.4 MSGRP RI Conclusions

Contaminated soils at the Industri-plex Site are impacting groundwater, which in turn discharges to and impacts the surface water and sediments of the HBHA Pond, the HBHA wetlands and the Aberjona River. Once in the Aberjona River, the contaminants, primarily arsenic, can migrate further downstream to depositional areas where they can precipitate and become part of the sediment bed load or possibly be re-suspended and continue their downstream migration. Surface water concentrations of arsenic were greatest in the Northern Study Area (i.e. between the Industri-plex Site and I-95).

Only areas in the northern portions of the MSGRP RI Study Area have been shown to present human health risk and hazards above EPA risk management guidelines and unacceptable ecological risks. At a minimum, cleanup alternatives should be developed in the Feasibility Study to address the areas and major risk contributors summarized in the following table:

HUMAN HEALTH RISK			
RISK AREA	SCENARIO/ RECEPTOR	IMPACTED MEDIA	MAJOR CONTAMINANT CONTRIBUTING TO RISK
Industri-plex Site (Reach 0)	Future Construction Worker	Groundwater	(NC) - Arsenic
Industri-plex Site / HBHA Pond Area (Reach 0)	Future Industrial Worker	Groundwater, Indoor air	(NC) - Benzene, naphthalene, arsenic (C)- Trichloroethene
Former Mishawum Lake & South of Cabot Road Area (Reach 0)	Future Industrial Worker	Groundwater, Indoor air	(C)- Trichloroethene
Industri-plex Site / HBHA Pond Area (Reach 0)	Future Car Wash Worker	Indoor air	(C)- Trichloroethene (NC) - Benzene, naphthalene
Former Mishawum Lake & South of Cabot Road Area (Reach 0)	Future Car Wash Worker	Indoor air	(C)- Trichloroethene
Wells G&H Wetland (Reach 1); and Former Cranberry Bog (upper Reach 2)	Current/ Future Recreational Exposure	Sediment	(C) – Arsenic (NC) - Arsenic
HBHA (Reach 0); and Wells G&H Wetland (Reach 1)	Future Dredger/ Construction Worker	Sediment	(NC) – Arsenic
Former Mishawum Lake Area (Reach 0)	Future Day Care Child (surface soil)	Soil	(C) – Arsenic
	Future Day Care Child (subsurface soil)	Soil	(C) – Arsenic
	Future Const. Worker (subsurface soil)	Soil	(NC) - Arsenic
ECOLOGICAL RISK			
HBHA Pond	Benthic Invertebrate Communities	Sediment, Deep surface water	Arsenic and Benzene

(NC) – Non-carcinogenic Hazard

(C) – Carcinogenic Risk

1.0 INTRODUCTION

This Multiple Source Groundwater Response Plan Remedial Investigation (MSGRP RI) report describes the investigations and data evaluation activities conducted to assess contamination in groundwater, surface water, sediment, and soil at the Industri-plex Superfund Site (Site) and surrounding area, and surface water and sediment in the Aberjona River (i.e. MSGRP RI Study Area). This report was prepared by the cooperative efforts of Tetra Tech NUS, Inc. (TtNUS) and Metcalf and Eddy, Inc. (M&E) for the United States Environmental Protection Agency (EPA) under Contract No. 68-W6-0045, Work Assignment No. 116-RICO-0107 and Contract No. 68-W6-0042, Work Assignment No. 101-RICO-0146, respectively.

This report was prepared in accordance with the Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA (EPA, 1988). It is consistent with the requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980, as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986; and the National Oil and Hazardous Substances Pollution Contingency Plan (NCP). This MSGRP RI is also consistent with the Commonwealth of Massachusetts' applicable and relevant environmental laws and regulations.

The Record of Decision (ROD) for the Industri-plex Site was issued in 1986 and addressed on-site soil, sediment, and groundwater contamination. The remedial investigation (RI) that supported the ROD focused on site-specific soil and groundwater "hot-spot" problems and did not attempt to identify other possible sources of either upgradient or cross-gradient groundwater contamination or impacts to surface water. According to the ROD, "...CERCLA guidance recognizes that specific decisions about groundwater remedial actions resulting from a CERCLA site should be made in conjunction with the resolution of the larger area-wide groundwater problem" (EPA, 1986). To fully understand the site-specific and area-wide groundwater issues, the ROD and the Consent Decree assigned separate responsibilities to the Settling Defendants and the EPA to conduct two additional studies. The Settling Defendants were required to implement the ROD-prescribed Groundwater/Surface Water Investigation Plan (GSIP) to assess the groundwater, surface water, and sediment contamination on the site. The EPA was required to implement the Multiple Source

Groundwater Response Plan (MSGRP) to evaluate area-wide contamination issues, outside of the GSIP study area.

As stated in the ROD, EPA believed that the MSGRP was the “most efficient response to the remediation of the groundwater problems associated with the Site as well as the larger problems within the aquifer” (EPA, 1986). The description of the selected remedy for groundwater noted that the findings and conclusions of the MSGRP would be used to develop and implement a final remedy for on-site groundwater problems (EPA, 1986).

The Remedial Design/Action Plan appended to the Consent Decree included a scope for the GSIP to develop site-specific information that EPA would then incorporate into the MSGRP. The GSIP scope was consistent with the following objectives of the MSGRP:

- Evaluate on-site and off-site conditions;
- Identify and characterize possible source areas; and
- Define the upgradient aquifer conditions influencing groundwater quality in that portion of the aquifer investigated during Stauffer’s 1984 remedial investigation (U.S. District Court, 1989).

The Consent Decree also stated that the results of the GSIP investigation would be incorporated into the MSGRP “leading to selection of a final remedy for area wide groundwater and surface water contamination” (U.S. District Court, 1989).

While the GSIP and MSGRP investigations were being conducted to assess contamination in and around the northern reaches of the Aberjona River, a separate investigation was being performed in association with the Wells G&H Superfund Site to assess surface water and sediment in the southern part of the river. The Aberjona River flows through the two Superfund sites, which are approximately 1 mile apart (see Figure 1-1). Site investigations have been conducted at the Wells G&H Superfund Site since 1979 and include studies that evaluated contamination of surface water and sediments in the Aberjona River and its associated wetlands.

In 2002, EPA decided to combine the separate surface water and sediment investigations being performed at the two Superfund sites into one study to more efficiently evaluate contamination and risk issues for the Aberjona River and ultimately develop one remedial decision for the entire river, if necessary. As a result, the MSGRP RI Study Area for surface water and sediments was expanded to include the southern reach of the Aberjona River from Interstate 95 (I-95) south, through the Wells G&H Site, to the Mystic Lakes. For discussion purposes, the Northern Study Area (northern portion of the expanded MSGRP RI Study Area) is generally defined as the area from the Wilmington/Woburn town line approximately 1.5 miles south to I-95; the Southern Study Area is generally defined as the Aberjona River and its associated wetlands from I-95 approximately 6 miles south to the Mystic Lakes (see Figure 1-1). These study areas are discussed in greater detail in the following sections.

Consequently, this MSGRP RI report presents and evaluates data from the investigations initially conducted for separate studies at the two Woburn, Massachusetts Superfund sites as described below:

- Industri-plex Superfund Site -- GSIP: Focused the investigation on groundwater, surface water, sediments, and soil at the Industri-plex Site and surrounding area, south to Mishawum Road and I-95;
- Industri-plex Superfund Site -- MSGRP: Incorporated the findings of the GSIP and focused the investigation on area-wide groundwater, surface water, sediments, and soil contamination including areas adjacent to the Industri-plex Site, south to Mishawum Road and I-95, and at specific locations along the Aberjona River south of I-95;
- Wells G&H Superfund Site -- Operable Unit 3 (OU-3), Aberjona River Study: Focused the investigation on surface water and sediment within the Aberjona River and its associated wetlands from I-95 south to the Mystic Lakes.

The investigations incorporated into the MSGRP RI were principally conducted by the EPA and the Settling Defendants under the auspices of the Industri-plex Site Remedial Trust (ISRT). The ISRT was created as a requirement of the 1989 Consent Decree for the 25 Settling Defendants (current and previous landowners) to form a single entity responsible for funding,

managing, and administering the remediation at the site and fulfilling the obligations of the Consent Decree.

Combining the Industri-plex Site GSIP and MSGRP investigations with the Wells G&H Site Aberjona River Study into one comprehensive RI/FS fulfils EPA's obligations under the 1986 Industri-plex Site ROD to evaluate other potential groundwater contaminant sources around the Industri-plex Site and assists EPA in making a remedial decision for the Aberjona River based on an evaluation of the river as a whole.

1.1 Purpose of Report

The overall objective of the MSGRP RI is to characterize the nature and extent of contamination and the risks posed by hazardous substances in the groundwater, surface water, sediments and soil at the Industri-plex Site; and in the surface water and sediment of the Aberjona River from the Industri-plex Site south through the Halls Brook Holding Area, beneath I-95, and through the Wells G&H Aberjona River Study Area to the Mystic Lakes. This information will then be used to prepare a Feasibility Study (FS) to evaluate potential remedial options, if necessary. Specific objectives of the MSGRP RI are to:

- Compile and evaluate available data and obtain additional data required to adequately characterize the MSGRP RI Study Area and determine the source, nature and extent of contamination in the groundwater, surface water, sediment, and biota;
- Assess the potential contaminant migration pathways and transport mechanisms and the environmental fate of contaminants of concern in the study area;
- Evaluate possible soil contamination adjacent to the Industri-plex Site boundary that may exceed previously established threshold values for the Industri-plex Site soil remedy and which may possibly require an expansion of the soil remedy; and
- Evaluate, through risk assessments, the potential threats to human health and the environment posed by study area contaminants. Separate baseline human health and ecological risk assessments (HHRAs/ERAs) were completed by EPA for the Industri-

plex Site MSGRP Study Area (Northern Study Area) and the Aberjona River Study Area (Southern Study Area). Based on the two separate HHRAs/ERAs, a comprehensive summary of the human health and ecological risks for the entire MSGRP RI Study Area is presented in this MSGRP RI.

1.2 **Report Organization**

This MSGRP RI report is comprised of three volumes. Volume I presents the text, including a discussion of investigation activities, results, and interpretations, as well as references. Volume II presents the tables and figures. Volume III presents the appendices.

The text is organized as follows:

- Executive Summary, provides a brief discussion of the principal findings of this MSGRP RI.
- Section 1.0, Introduction, discusses the purpose and scope of the MSGRP RI, describes the MSGRP RI Study Area, and summarizes the study area background and history.
- Section 2.0, MSGRP RI Study Area Investigations, summarizes the investigations conducted and evaluated for this RI.
- Section 3.0, Physical Characteristics of the MSGRP RI Study Area, presents descriptions of surface features, geology, hydrogeology, surface water hydrology, wetlands, floodplains, and climate.
- Section 4.0, Nature and Extent of Contamination, discusses the potential contaminant sources and contaminant presence and distribution in groundwater, surface water, sediment, soil, and biota in the study area.
- Section 5.0, Contaminant Fate and Transport, presents an interpretation of potential contaminant migration pathways and transport mechanisms.
- Section 6.0, Human Health Risk Assessment (HHRA) Summary, presents a summary of the HHRAs completed for the Industri-plex Site and Aberjona River Study Area.
- Section 7.0, Ecological Risk Assessment (ERA) Summary, presents a summary of the ERAs completed for the Industri-plex Site and Aberjona River Study Area.
- Section 8.0, Conclusions, presents the findings of the MSGRP RI.

1.3 MSGRP RI Study Area

This section presents a description and history of the MSGRP RI Study Area. The MSGRP RI Study Area, as defined for this report, includes the area from the Wilmington/Woburn town line south to I-95 (Northern Study Area) and from I-95 south to, and including, the Mystic Lakes (Southern Study Area) (Figure 1-1).

Section 1.3.1 provides a physical description and land use history of the Northern Study Area including a detailed description of the study area's most prominent feature, the Industri-plex Superfund Site. Similarly, Section 1.3.2 provides a physical description and land use history of the Southern Study Area. Section 1.3.3 presents a chronology of the environmental action and enforcement history of the MSGRP RI Study Area.

1.3.1 Northern Study Area Description and History

This section contains a description of and historical information on the Northern Study Area. The Northern Study Area includes the area from Wilmington/Woburn town line south through the Industri-plex Superfund Site to I-95 (Figure 1-1).

The Northern Study Area encompasses a large area surrounding the Industri-plex Superfund Site that could potentially impact groundwater and surface water on the site. The MSGRP described the 1986 ROD required EPA to conduct investigations of area-wide groundwater issues in this study area. One such study researched historical and current land use and identified potential sources of contamination to groundwater and the Aberjona River within the Northern Study Area. The report that summarized these findings, the *Preliminary Multiple Source Groundwater Response Plan (MSGRP) Report* (HNUS, 1997), serves as the basis for the following information.

1.3.1.1 Northern Study Area Current Land Use

Current land use in the Northern Study Area is mixed, including residential, industrial, and commercial uses, with the majority of the area – including nearly all land immediately surrounding the Industri-plex Site – developed for industrial and commercial use. In 1997, an

“open space” designation was added to the Woburn zoning ordinance. The only significant parcel of land designated as “open space” within the Northern Study Area is the Halls Brook Holding Area (HBHA) (Woburn Zoning Map, 2002).

The industrial land use represents the most significant threat to groundwater and surface water quality in the study area because of the wide variety of associated activities that use and dispose of chemicals and other hazardous compounds. The majority of the industrial land use in Woburn is in the northern portion of the city. Based on a review of "The Directory of New England Manufacturers", the types of manufacturers or businesses that are located in Woburn include:

- Food Processing
- Machine Shops
- Equipment Handling and Warehouse
- Data Control Equipment
- Microwave and Semi-Conductor
- Leather Industry
- Auto Body Repair
- Gasoline Service Station
- Electro-Manufacturing
- Computer & Office Equipment
- Equipment Repair
- General Manufacturing
- Chemical Manufacturing and Distribution
- Printing
- Metal Plating
- Wood Recycling
- Photographic Processing
- Dry Cleaning
- Pharmaceutical Research & Design

One municipal sanitary landfill, the Woburn Sanitary Landfill, is located within the Northern Study Area. Located off Merrimac Street in Woburn, the landfill is a 54-acre solid waste disposal area. The site was originally mined for sand and gravel through the 1960s. The site was used as a landfill beginning in 1966, when it received tens of thousands of cubic yards of refuse mined from an existing city landfill (the Allstate Sand and Gravel Dump) that was being developed into the Woburn Industrial Park (HNUS, 1997). The refuse material was used to fill the erratic topography left by the sand and gravel mining operation. The landfill officially ceased operating in June 1986.

In 1988, the City of Woburn entered into a consent order with the MADEP to investigate and formally close the landfill. Following several years of plan submittals, negotiations, and periods of inactivity, the City of Woburn and the MADEP entered into another consent order in June of 1996. The new consent order required that the landfill closure be completed by September of

2000. An Initial Site Assessment was completed in January 1997. The City of Woburn completed the first quarterly sampling round in March of 1997 to support a Comprehensive Site Assessment. Construction of the landfill cap was completed in 2003. The City of Woburn continues to monitor local groundwater and provide periodic status reports to the MADEP.

1.3.1.2 Northern Study Area Historical Land Use

Historical land uses within the study area have included agricultural, industrial, and residential uses. Agricultural activities included operating piggeries and raising cattle and crops. The Roketenetz piggery, located at the confluence of Halls Brook and the Aberjona River, was reported to have been the source of some pollution in the form of stock yard runoff to Woburn surface waters (CDM, 1967).

During the period from 1953 to 1965, the City of Woburn disposed of its solid waste at an open dump operated by Allstate Sand and Gravel. The dump was located north of Mishawum Road, southeast of New Boston Street, and west of the Boston & Maine (B&M) Railroad (Geotrans, 1987). The dump was operated as an open burning dump until May of 1962, when the owners entered into an agreement with the Woburn Board of Health requiring that the trash be covered with earthen materials and not be burned. Despite the order and in an effort to control or stop the spontaneous fires, the owners left a fire hose running all night to control the fires. This practice increased the production of leachate from the refuse. The dump was finally closed by order of the state in 1968.

The types of industries that have historically operated in the Northern Study Area included chemical manufacturing, rendering, and machine shops. The most prominent industrial activity within the Northern Study Area was a chemical manufacturing facility, which operated from 1853 through the 1960s under a variety of ownerships including the Woburn Chemical Works, Merrimac Chemical Company, Monsanto Chemical Company, and Stauffer Chemical Company. During the 1970s, this property became the focus of a Superfund cleanup action known as the Industri-plex Superfund Site. Section 4.1 of this report includes a discussion of industries and other activities that were evaluated in prior studies (HNUS, 1997) as potential sources of contamination to the Northern Study Area. These studies evaluated other area-

wide sources of potential contamination in Woburn and also in south Wilmington, just north of the Industri-plex Site (e.g. National Polychemical Company/Olin Chemical, E.C. Whitney, Ritter Trucking).

Property development in the area has resulted in alterations to the course of the Aberjona River. Development activities in the early 1970s resulted in the filling-in of Mishawum Lake, the creation of the Halls Brook Holding Area, and the redirection of the river into a continuous open channel flowing between two lanes of Commerce Way. A portion of the surface flow from the South Pond was diverted to the Created Wetland as part of the Industri-plex Site soil remedy (constructed in 1996). Flow from the Created Wetland now discharges to the upper portion of the Atlantic Avenue Drainway, an open channel/ditch constructed to receive surface drainage from Atlantic Avenue and the surrounding developed properties (see Figure 1-1). Historical and current drainage patterns of the river are discussed in Sections 3.4.2 and 3.4.3, respectively.

1.3.1.3 Industri-plex Superfund Site Description and History

The following historical information was summarized from the Industri-plex Site ROD (EPA 1986); the Phase I Report (Stauffer, 1983); the Ground-Water/Surface Water Investigation Plan (GSIP), Phase I Remedial Investigation Final Report (Roux, 1991); and the Preliminary Multiple Source Groundwater Response Plan (MSGRP) Report (HNUS, 1997).

The Industri-plex Superfund Site is a 245-acre industrial park located in the northeast corner of Woburn, Massachusetts near the intersection of two major highways, I-93 and I-95 (Figure 1-1). Interstate 93 runs north/south along the eastern border of the site. I-95 runs east/west approximately 4000 feet south of the site. The site is bordered to the north, south and west mainly by commercial and light industrial properties. The Aberjona River flows through a portion of the site. Several associated tributaries, drainways, and wetlands also traverse or are situated on the site. A commuter rail line, oriented approximately north/south, crosses the western side of the site.

The nearest residences are located approximately three quarters of a mile north of the site along Eames Street in Wilmington, approximately 1000 feet east of the site along Arnold Road

in Reading, approximately 2500 feet west of the site in a residential area off of Merrimac Street in Woburn, and approximately 4000 feet south of the site off Mishawum Road and Washington Street in Woburn. According to EPA, approximately 34,000 people live within 3 miles of the site.

The property was undeveloped land prior to 1853. The northern third of the site was covered mainly by forest and the southern two thirds were comprised mainly of wetland and marshy swamp land. From 1853 through 1933, the site was home to various chemical manufacturing operations of the Woburn Chemical Works and its successors, including the Merrimac Chemical Company, New England Manufacturing Company, Monsanto Chemical Works, and the Stauffer Chemical Company (Stauffer, 1983).

From 1853 through about 1899, Woburn Chemical Works and Merrimac Chemical Company principally produced chemicals for the local textile, leather and paper industries; the main products were sulfuric acid and related chemicals. Sulfuric acid was a major product of Merrimac Chemical between the 1880s and 1920s (Aurilio, et al., 1995). Sulfur-containing ores were used to produce sulfuric acid. The pyrite ores used by manufacturers of sulfuric acid contained impurities, including zinc, copper, lead, calcium, magnesium, and arsenic (Aurilio, et al., 1995).

In 1899 Merrimac Chemical purchased the William H. Swift Company of East Boston, a producer of arsenic insecticides, acetic acid, and dry colors. By 1900, Merrimac Chemical had developed more than 400 acres and was one of the largest producers of chemicals in New England (Durant, 1991). Between 1899 and 1915, Merrimac Chemical became the leading U.S. producer of arsenic pesticides. Production of lead arsenate pesticides peaked about 1918; sodium arsenate, used in the production of lead arsenate, was produced by Merrimac Chemical until 1928 (Aurilio, et al., 1995). In 1915, Merrimac Chemical started a separate company on the site, the New England Manufacturing Company, to produce munitions for World War I (Stauffer, 1983). New England Manufacturing produced organic chemicals including phenol, benzene, picric acid, toluene, and trinitrotoluene (TNT).

In 1929, Merrimac Chemical was purchased by Monsanto Chemical Works. Merrimac Chemical continued to operate at the site until 1931, as the Merrimac Division of Monsanto.

During this period, the facility became a rendering factory (Durant, 1991). By 1931, Merrimac's Woburn operations were mostly consolidated to a plant in Everett, Massachusetts. From 1931 to 1934 no operations were conducted on the site.

During the period that the site was used for chemical manufacturing, development was characterized by numerous small buildings scattered over 90 acres in the western portion of the site. Figure 1-2 presents the extent of Merrimac Chemical's operations in 1926. Historical research and a review of old maps of the site show that these buildings were built and destroyed regularly as demand changed for certain chemicals. Waste products from the chemical operations were apparently disposed of over a wide area encompassing all the property owned by Merrimac Chemical west of the current location of Commerce Way, including land west of the railroad tracks. The wastes were reportedly used for two main purposes: to fill low or wet areas in order to provide more usable land to build on, or to build dikes and levees to contain liquid wastes in particular areas (EPA, 1986).

In 1934 the property was sold to New England Chemical Industries, which constructed a glue manufacturing plant on the site. The plant began operating in 1935, manufacturing glue from animal hides. Glue manufacturing continued until mid-1969 under the ownership of New England Chemical Industries (1934-1936), Consolidated Chemical Industries (1936-1961), and Stauffer Chemical Company (1961-1969). Stauffer ceased operations, completed equipment removal, and vacated the site in 1969 (EPA, 1986).

The glue manufacturing process involved boiling raw animal hides, hide fleshings, or chrome-tanned leather scraps to extract the protein collagen, then concentrating the extracts through evaporation and drying. Once dry, the resulting glue was ground up and bagged for shipment. Liquid effluent from the manufacturing process exited the building, flowed through a grease and oil separator, and into a primary settling lagoon before discharging to a city sewer line. Solid wastes from the glue manufacturing process were disposed of on site. The solid wastes disposed included tankage (material such as wood shavings, raw products, and hide materials remaining in the bottom of the tank after cooking), hides, and sludge periodically removed from the settling lagoon (EPA, 1986).

Disposal practices for the glue manufacturing by-products were similar to those for the chemical manufacturing wastes, but disposal of the glue wastes was limited primarily to the areas east and southeast of the main facility (EPA, 1986). Frequently the glue production wastes were buried directly on top of the chemical manufacturing wastes. Over the 35 years of operations, the glue waste deposits reached heights of 40 to 50 feet above natural grade and covered several acres east of the plant (EPA, 1986).

In December 1968, the Mark Phillip Trust (MPT) purchased about 149 acres of the property from Stauffer Chemical Company, while others purchased the remaining 35 acres (Roux, 1989). The MPT intended to develop the Stauffer land, along with land it owned to the south and east, as an industrial park to be called Industri-plex 128. The MPT began development in the early 1970s on the southern-most section of its property near Mishawum Road and Route 128 (I-95). Development activities involved filling and excavating portions of the property to facilitate the sale of various parcels. Development continued northward in phases and reached the southern end of the site in 1975.

Excavations during development of the property in the 1970s uncovered chemical and glue manufacturing wastes, including decaying animal hides. These waste deposits were excavated and either trucked off site, buried on the Boston Edison right-of-way (BECO ROW) south of the site, or stockpiled in two piles on the sides of a small pond on the northern border of the site (EPA, 1986). These two stockpiles, or “hide piles” as they came to be known, are referred to as the West and East Hide Piles, and ultimately filled much of the pond and reached dimensions of up to 40 feet high, 250 feet long, and 100 feet wide (EPA, 1986). In addition to the East and West Hide Piles, two other hide piles formed during previous chemical and glue manufacturing operations were located on the site: the East-Central Hide Pile, located just north of the present intersection of Commerce Way and Atlantic Avenue, and the South Hide Pile, located south of the Atlantic Avenue Drainway. An aerial photograph from 1963 (Figure 1-3) shows large areas of fill in these general locations (EPA, 1998). The South Hide Pile was reportedly the original location where hide residues were buried during operation of the glue plant (Stauffer, 1983). The four hide deposits on the site encompassed approximately 13 acres and an estimated volume of 341,000 cubic yards (Stauffer, 1985).

Despite enforcement actions filed by state and federal regulatory agencies, the MPT continued development and disturbance of the buried wastes until 1979 when an injunction was issued to stop further development. (See Section 1.3.3 for additional details of the site's environmental action and enforcement history.) Changes in the site as a result of site development activities can be seen in Figure 1-3, which presents historical aerial photographs of the site and surrounding area from 1938 to 1995 (EPA, 1998). The buildings associated with the operations of Consolidated Chemical (1938 photograph) and Stauffer Chemical (1963 photograph) can be seen in the center of each photograph. The area around the site appears generally undeveloped in the 1971 photograph. Significant development can be seen north and south of the Industri-plex Site in the 1995 photograph.

The site was listed on the Superfund Interim List of 115 Top Priority Hazardous Waste Sites in 1981 and on the Superfund National Priorities List in 1983. In 1986, EPA completed a Record of Decision (ROD) that selected a cleanup remedy for the site. The cleanup remedy included capping contaminated soils and hide piles (soil remedy); constructing an impermeable cap and a gas collection and treatment system at the East Hide Pile (air remedy); constructing an interim groundwater treatment system for benzene and toluene "hot spot" areas (interim groundwater remedy); implementing institutional controls to restrict future use of the property; and further investigating groundwater, surface water, and sediment contamination at the site and surrounding area (GSIP and MSGRP investigations). In 1989 EPA entered into a Consent Decree with the Settling Defendants and the ISRT was established to fund, implement, and administer the selected remedy. Since that time the ISRT has constructed the soil remedy and conducted further GSIP-related studies. Also since 1989, the site has undergone additional development. (See Section 1.3.3 for additional details of the site's environmental action and enforcement history.)

The site is currently home to numerous active commercial and light industrial businesses as well as the Anderson Regional Transportation Center, which was constructed on the site in the late 1990s and opened in May 2001 (see Figure 1-4). The Anderson Regional Transportation Center is a 33-acre commuter transportation hub featuring 2,400 short- and long-term parking spaces, a commuter rail station, Logan Express bus terminal, and vanpool, carpool, and bus services.

Most of the developed land on the site is covered with buildings, asphalt, concrete, or other covers that prevent human contact with contaminated soils. As of 2004, approximately 25 percent of the site remains undeveloped; the undeveloped areas include the capped hide piles and wetland mitigation areas. Access to the East-Central hide pile is further restricted by chain-link fencing, which is also inspected regularly and maintained by the ISRT.

In addition to the commercial developments, the Massachusetts Highway Department constructed a new interchange to I-93 along the eastern border of the site that connects to Atlantic Avenue and Commerce Way. Also, the City of Woburn completed an extension and improvements to Commerce Way, which bisects the site. Significant drainage improvements were also constructed during these projects, including culverting of approximately 1,800 feet of the Aberjona River. The new interchange and Commerce Way extension, completed in October 2000, provide improved access to the Anderson Regional Transportation Center and other businesses on the site and surrounding area. This improved access has encouraged the development of new commercial and retail space, including a hotel, office buildings, a large department store, and restaurants.

1.3.2 Southern Study Area Description and History

Under the MSGRP, EPA was responsible for conducting investigations of area-wide groundwater issues. The merger of the surface water and sediment portion of the Industri-plex MSGRP with the Wells G&H OU-3 Aberjona River Study resulted in an expanded study area and prompted the need for a study similar to the 1997 *Preliminary Multiple Source Groundwater Response Plan (MSGRP) Report*. This new study focused on potential sources of contamination to the Aberjona River in a study area south of I-95, including the Wells G&H Site and Aberjona River, extending south to the Mystic Lakes. The report that summarizes the findings of this study, the *Draft Preliminary MSGRP Supplemental Report – Southern Area* (TtNUS, 2003), serves as the basis for the information presented in the following sections.

The Southern Study Area is defined as the Aberjona River, its associated tributaries, ponds, lakes, and wetlands within its floodplain, from I-95 in Woburn to the north, to the Mystic Lakes in Arlington to the south. The Aberjona River is the primary river system within the Aberjona River watershed and has a drainage area of approximately 25 square miles (Solo-Gabriele,

1995). The Aberjona River originates in a low-lying wetland area in Reading, Massachusetts (the northeast area of the watershed) and flows for approximately 10 miles in a southward direction discharging into the Mystic Lakes in Winchester, Massachusetts (Figure 1-1). The river flows through a highly-developed urban area along its entire length. Industrial areas are concentrated in Woburn; other land uses contiguous to the river include park lands, residential, urban and light industrial areas. The Aberjona River is classified as a Class B surface water, defined by MADEP as a “habitat for fish, other aquatic life, and wildlife, and for primary and secondary contact recreation” (314 CMR 4.05(3)(b)).

From the north, the river flows through the Industri-plex Superfund Site and adjacent to the HBHA, which provides storage for Halls Brook and surrounding wetlands during elevated flow events (CDM, 1999). At Mishawum Road the river combines with the outflow from the HBHA and then flows south under I-95, discharging into a 38-acre wetland adjacent to Woburn’s municipal wells, Wells G&H (Figure 1-1). Near Olympia Avenue and just north of municipal Well H, the river splits into two main channels that converge approximately 1,000 feet downstream from the divergence. After flowing south through the Wells G&H Superfund Site, the Aberjona River continues through a 17-acre former cranberry bog, now a conservation area. The river continues through channelized reaches into Winchester and through several residential and municipal areas, including a major business area in the town center (CDM, 1999). The river finally drains into the Upper Mystic Lake (Figure 1-1).

1.3.2.1 Southern Study Area Current Land Use

Since the Southern Study Area is generally defined as the Aberjona River, the following current and historical land use discussions are focused on developed lands adjacent to the Aberjona River.

The Southern Study Area is highly urbanized. A 1992 study by the Metropolitan Area Planning Council (MAPC), North Suburban Water Supply Protection Plan, indicated that the general Southern Area is approximately 50 percent developed land and 50 percent undeveloped land (MAPC, 1992). Developed land use is mixed, including residential, industrial, and commercial office park. Based on 1985 data (MAPC, 1992) the majority of the developed land in Woburn and Winchester is residential (86 and 90 percent respectively). Commercial developments

represent less than 10 percent (9 percent in Woburn and 6.5 percent in Winchester), while industrial land use represents less than 5 percent in Woburn and approximately 3.5 percent in Winchester.

Commercial developments include nurseries and greenhouses. There is a public golf course in Woburn, located west of Horn Pond. The majority of the industrial land use is in the northern and central portions of the Southern Study Area, specifically in the southwest portion of Woburn and the northern portion of Winchester.

Based on data extracted from "2002 Harris Massachusetts Manufacturers Directory", the types of manufacturers or businesses, categorized by primary Standard Industrial Code (SIC), that are located in the Woburn and Winchester portions of the Southern Study Area are as follows (Harris, 2002):

- | | |
|---|--|
| • Food and Kindred Products | • Machinery (except electrical) |
| • Apparel and Textile Products
(made from fabrics) | • Electrical and Electronic
(machinery, equipment, and surplus) |
| • Lumber and Wood Products
(excluding furniture) | • Transportation Equipment |
| • Furniture and Fixtures | • Measuring, Analyzing, and Controlling
Instruments |
| • Printing, Publishing, and Allied
Industries | • Miscellaneous Manufacturing
Industries |
| • Chemicals and Allied Products | • Wholesale Trade - Durable Goods |
| • Rubber and Miscellaneous Plastic
Products | • Business Services |
| • Stone, Clay, Glass, and Concrete
Products | • Miscellaneous Repair Services |
| • Fabricated Metal Products
(except machinery and transportation
equipment) | • Engineering Research Management
and Related Services |

Only SIC categories for facilities present in the Southern Study Area are listed in the table. For example, there are currently no leather and leather products facilities (SIC 31) located in the Southern Area. The number of chemical manufacturers in the Southern Area has declined. Three facilities in Woburn are currently classified in SIC 28 – chemicals and allied products.

The facilities produce skin care products (SIC 2844), polymers and medical grade tubing (SIC 2821), and coatings and adhesives (SIC 2851).

General manufacturing facilities, such as manufacturers of clothing (SIC 23), rubber and plastic products (SIC 30), stone, clay, glass and concrete products (SIC 32), wood products (SIC 24), and fabricated metal products (SIC 34), are present in small numbers.

1.3.2.2 Southern Study Area Historical Land Use

From the late 1600's to the 1980's the predominant land uses in the area were agricultural, industrial, and residential uses. Agricultural activities included piggeries and raising cattle and crops. The Murphy piggery, located approximately 1,500 feet northeast of Woburn's former municipal Well H, had been reported as a source of pollution in the form of stock yard runoff to Woburn surface waters (CDM, 1967).

A large cranberry bog in Woburn, located between Salem Street and Washington Street Circle, operated from 1910 to 1939. The cranberry bog is presently a conservation area maintained by the Woburn Conservation Commission with financial assistance from the Massachusetts Department of Natural Resources. Based on aerial photos from 1938 to 1969 and "anecdotal" references, it is possible that apple orchards may have existed within the MSGRP RI Study Area. Two possible apple orchards were located at Wildwood Avenue and just south of I-95 on Washington Street. However, based on a review of the City of Woburn Assessor's records of past ownership of the properties, and also on discussions with the present owners of the properties, there are no actual records of apple orchards previously located at the two properties.

Historically, the leather industry was a significant industrial presence in the entire MSGRP RI Study Area. The earliest tannery was built in Woburn in 1666. Approximately 100 tanneries, rendering factories, and leather-finishing companies have operated in Woburn, Stoneham, and Winchester at various times between 1838 and 1988. In addition to the John J. Riley Company (a former leather tannery located on Salem Street, Woburn), 37 other leather tanning/finishing/ rendering factories were located within the Southern Study Area and

adjacent lands (TtNUS, 2003). Few leather tanneries or finishers continued operating beyond the 1930's; the John J. Riley company, however, remained in operation until 1988.

Between the 1870's and 1920's, the leather industry accounted for more than half of the total annual value of goods produced in the Aberjona River watershed (HNUS, 1997). The most productive period for the tanning industry occurred from the late 1870's to the 1920's; by approximately 1925 the tanning industry had reached its peak (Spliethoff and Hemond, 1996). Surface water contamination, attributed to tanning and finishing operations, was reported as early as 1871. This contamination was the result of the direct discharge of tanning wastes into surface waters (Durant, et al., 1990).

The first major sewer line in the Southern Area was installed in 1878 along the Aberjona River in Winchester. The City of Boston constructed this sewer line, referred to as the "Old Mystic Valley Sewer," to prevent contamination of the Upper Mystic Lake, which between 1864 and 1898 served as the local drinking water supply. The sewer line transported wastewater from tanneries located in Winchester Center south through Winchester, diverted it away from the Upper Mystic Lake, and finally discharged the wastewater into the Lower Mystic Lake. Although the wastewater was treated before discharge to the Lower Mystic Lake, the water quality of the lake eventually began to deteriorate. The Lower Mystic Lake was used as a discharge area until 1895. Because the "Old Mystic Valley Sewer" could not handle the volume of wastes generated by adjacent tanneries and other industries, the sewer line was extended in 1895 and connected with other sewer lines that discharged to Deer Island and Boston Harbor (Durant, et al., 1990).

The "Old Mystic Valley Sewer" initially did not extend to north Woburn. Tanneries that were not connected to a sewer line collected their wastes in lagoons. The solids settled out and the wastewater was discharged directly into surface water bodies such as the Aberjona River and its tributaries. It was not until 1927 that construction began on the Metropolitan District Commission (MDC) sewer extension to north Woburn. This sewer line did not begin operating until 1932 due to problems caused by excessive groundwater infiltration (Durant, et al., 1990).

After the completion of the MDC sewer extension in 1932, much of the tannery waste from facilities in north Woburn was discharged to the sewer system. However, capacity limits and

periodic plugging of the sewer lines due to high concentrations of solids in the tannery wastewater resulted in periodic overflows. Settling lagoons were eventually used to pre-treat the tannery wastewater prior to discharge into the sewers. These lagoons generated a large volume of sludge that was periodically removed and disposed of in centrally located landfills or on-site disposal areas (Durant, et al., 1990).

1.3.3 Study Area Environmental Action and Enforcement History

This section summarizes the history of environmental cleanup and enforcement actions associated with the Industri-plex Superfund Site in the Northern Study Area and with the Wells G&H Superfund Site in the Southern Study Area.

1.3.3.1 Northern Study Area

The following historical information was summarized from the Industri-plex Site ROD (EPA, 1986), the Preliminary Multiple Source Groundwater Response Plan Report (HNUS, 1997), and the Industri-plex Superfund Site page on the EPA New England Web Site.

There is a history of environmental complaints and enforcement actions associated with the Industri-plex Site, beginning in 1969 and continuing through the 1990s. The site was acquired by the Mark Phillip Trust (MPT) in December 1968 with the intent of developing the site and adjacent properties to the south into the Industri-plex 128 industrial park. The MPT commenced site development activities (e.g. land clearing and filling of wetlands) in 1969, which subsequently became the subject of numerous environmental and health violations.

The Commonwealth of Massachusetts' enforcement actions against the MPT began in 1969 when the MPT started development without the proper permits from the Massachusetts Department of Natural Resources (DNR). In December 1970 the DNR issued a permit to the MPT requiring that the former Stauffer Chemical wastewater settling lagoon and waste disposal areas on the site be managed to comply with current state regulations (EPA, 1986).

Disturbance of the decaying animal wastes during development of the site in the 1970s released strong and pervasive odors throughout the area and resulted in repeated complaints

by local citizens as well as numerous notices of violations issued by the Massachusetts Department of Environmental Quality Engineering (DEQE) for improper handling of wastes (EPA,1986). After repeated violations of DEQE's administrative orders, the Massachusetts Office of the Attorney General filed suit against the MPT on behalf of DEQE. At approximately the same time, the Town of Reading filed a similar suit. The two suits were merged and in 1977 the Superior Court issued an order prohibiting the MPT from disturbing two small parcels of land where the bulk of the remaining glue manufacturing wastes were believed to be buried (EPA, 1986). The order was only partially successful since the animal wastes that the MPT had already excavated and stockpiled continued to release substantial odors.

In June 1979 the United States Attorney's Office, on behalf of the U.S. Army Corps of Engineers and EPA, filed suit against the MPT for violations of Section 404 of the Federal Water Pollution Control Act (for illegal filling of wetlands). The suit resulted in an injunction issued in 1979 to stop further development activity due to concerns regarding contamination of the Aberjona River and the depletion of flood storage areas: the MPT had begun filling the North and South Ponds with borrow materials excavated from other areas of the site. According to reports from the Woburn Conservation Commission, these fill materials included animal hide wastes and chemical sludges (D'Annolfo, 1977).

In 1980, the MPT entered into a Consent Decree and an Agreement for Judgment with the U.S. Army Corps of Engineers and the DEQE, respectively. Under these agreements, the MPT was to discontinue site development and make alterations to the surface waters to protect the Aberjona River from site contamination and to prevent potential flood control problems.

In November 1980 the DEQE conducted a removal action at the site. The action involved application of a sprayed latex cover over a large exposed arsenic and lead deposit to minimize air entrainment of arsenic and lead dust.

In the summer of 1981 the EPA conducted a removal action which involved installing a chain link fence around the site to prevent unauthorized access. EPA conducted a subsequent removal action in June 1986 to repair the fence.

In October 1981 the site was listed on the Superfund Interim List of 115 Top Priority Hazardous Waste Sites. The site was listed on the National Priorities List of hazardous waste sites in September 1983.

In May 1982 DEQE and EPA entered into a Consent Order with Stauffer Chemical Company under which the company agreed to conduct a Remedial Investigation/Feasibility Study (RI/FS) and pay for its apportioned share of the remedial actions. Stauffer submitted a Phase I RI/FS report in April 1983 and a Phase II RI/FS report in April 1985. The RI/FS documented the nature and extent of contamination and the health risks associated with contaminants in site soils, the hide piles, and groundwater beneath the site, and also evaluated cleanup alternatives.

In 1985, after years of negotiations between the MPT and the federal and state regulatory agencies, separate federal and state Consent Decrees were approved. The decrees, which were similar in scope, required the MPT to determine the nature and extent of hazardous waste problems at the site, clean up the hazardous waste problems identified, and resolve the wetland filling issues. In exchange, the MPT would be allowed to develop certain pieces of the property to generate enough revenue to complete the investigations and site clean up. Citing the inability to generate sufficient capital, the MPT never complied with the conditions of the Consent Decrees (EPA, 1986).

In September 1986, EPA completed a ROD that selected a cleanup remedy for the site. The cleanup remedy included: 1) design and construction of permeable caps over 105 acres of soil and sediments contaminated with lead, arsenic, and chromium, including the West, East-Central, and South Hide Piles; 2) design and construction of an approximately 5-acre impermeable cap with a gas collection and treatment system over the East Hide Pile; 3) design and construction of an interim groundwater treatment system to treat a groundwater hot spot contaminated with toluene and benzene; 4) performance of a groundwater and surface water investigation plan (GSIP) to evaluate the degree of groundwater and surface water contamination from the site; and, 5) implementation of institutional controls to restrict future land use on the site to preserve the effectiveness of the remedy and allow property owners the fullest possible use of their property.

In addition to selecting a site cleanup remedy, the ROD required EPA to conduct a Multiple Source Groundwater Response Plan (MSGRP). The purpose of the MSGRP was to investigate potential contamination impacts from both site and off-site sources on the area-wide groundwater and surface water in the Aberjona River Watershed and to determine whether additional remedies were required for groundwater in the Industri-plex study area. The MSGRP RI would incorporate the GSIP data collected by the ISRT with the data collected for the MSGRP and serve as a comprehensive RI/FS to support a second ROD for the aquifer and any residual surface water and sediment contamination within the Industri-plex study area.

In April 1989, EPA entered into a Consent Decree with the Industri-plex Site Settling Defendants, which was comprised of successor entities to Monsanto and Stauffer Chemical, and 18 other landowners. Under the auspices of the Consent Decree, the ISRT was created as a single entity representing the Settling Defendants with responsibility for the coordination and implementation of the cleanup remedy selected in the 1986 ROD. Also, as part of the Consent Decree settlement, the MPT agreed to transfer ownership of land within the site to a trust in exchange for indemnification from future financial and civil liability. The Consent Decree also ordered the formation of the Industri-plex Custodial Trust, which was charged with the management of the former MPT land until the land could be sold and proceeds applied to the remedial efforts at the site.

Remedial actions and other activities taken to fulfil the requirements of the ROD and Consent Decree are summarized below:

Soil Cover Remedy and Gas Collection and Treatment System

Design of the soil cover remedy (consisting of approximately 105 acres of permeable and 5 acres of impermeable caps) was completed in 1992 and construction of the remedy began in 1993. In 1996 EPA approved a modification to the permeable cover design to accommodate construction of the Anderson Regional Transportation Center on approximately 36 acres of the site. Construction of the soil cover remedy, including the alternate cover for the transportation center, was completed in early 1998. Construction of the Regional Transportation Center was completed in spring 2001. Construction certification reports, which document the proper

installation of the caps, have been submitted to EPA in draft form and remain to be completed for all properties.

Construction of the gas collection and thermal oxidation treatment system at the East Hide Pile was completed and made operational in 1994. Minor modifications to the treatment system were completed in 1999 to allow the system to operate on an automated and intermittent basis due to the low concentrations of methane and hydrogen sulphide being generated under the cap. The system continues to function on the modified operational schedule.

Interim Groundwater Treatment System

The ISRT initially submitted a design for an area-wide groundwater extraction and treatment system in-lieu of the interim “hot spot” treatment systems required in the ROD and Consent Decree. However, in October of 1992, due to disagreement with EPA over the required effluent treatment standards, the ISRT withdrew their 95 percent design and reverted to the requirements of the ROD and Consent Decree, which called for interim treatment of the three “hot spot” groundwater plumes and selection of a comprehensive remedy at the conclusion of additional area-wide groundwater investigations.

In early 1993, the ISRT submitted a proposal for the use of an innovative technology, air sparging. A pilot system was installed in the summer of 1993, which led to the submittal of a design for a full-scale system in the fall of 1993. The in-situ air sparging treatment system was installed and briefly operated in the spring/summer of 1994 when it was abandoned because of operational problems related to uncontrolled excursions of injected air. During the remainder of 1994 the ISRT completed three pilot studies to evaluate different in-situ groundwater treatment technologies, including enhanced air sparging, oxygen injection, and a reactive permeable ferrous iron wall. The ISRT subsequently selected an oxygen injection technology and designed modifications to the existing air-sparging system to accommodate the new technology.

In September 1995, the ISRT submitted a proposed plan to EPA to operate the system for 1 year to evaluate the system’s performance prior to selecting the technology as a final remedy. Based on available data, EPA expressed concerns that this technology might not be

technically applicable or cost effective at this site. EPA gave conditional approval of the demonstration study with a requirement to implement a more comprehensive monitoring program during the testing phase than what the ISRT had proposed. The ISRT disputed EPA's monitoring requirement; the demonstration project was never initiated. No other actions have been taken to date regarding interim groundwater treatment. EPA will evaluate the results of the MSGRP RI and determine the next steps for the interim groundwater remedy.

Groundwater and Surface Water Investigation Program

To meet the requirements of the GSIP as stipulated in the Consent Decree, the ISRT completed two phases of groundwater and surface water investigations. The ISRT also completed an additional phase of investigation, referred to as the Final GSIP Scope of Work (Final GSIP SOW) to address data gaps identified from the Phase I and Phase II studies. Details of the GSIP investigations are presented in Section 2.1 of this RI report.

The ISRT completed the GSIP Phase 1 work and submitted their findings in the GSIP Phase 1 report dated June 7, 1991. Following their review, EPA identified several areas of concern regarding the report's conclusions and supporting data and granted conditional approval of the GSIP Phase 1 report. The conditions of the approval included the completion of additional investigations to fill data gaps and fully characterize the nature and extent of groundwater, surface water, and sediment contamination and address EPA's concerns regarding the Phase I report's findings. The ISRT agreed to collect additional data and address EPA's concerns in the GSIP Phase 2 investigation and report.

The ISRT completed the GSIP Phase 2 work and submitted their findings in the GSIP Phase 2 report dated May 29, 1992. EPA submitted comments on the GSIP Phase 2 report in December 1996. The comments again identified significant concerns with the findings presented in the report. As with the GSIP Phase 1 report, the major concerns with the Phase 2 report included the interpretations of groundwater flow, contaminant distribution, and the overburden/bedrock interface. Additional EPA concerns related to the ecological risk methods and interpretation of results, including the extent of sediment contamination and sediment toxicity.

Since the ISRT failed to resolve the issues raised by EPA in the GSIP Phase 1 and 2 reports, EPA concluded, and informed ISRT in May 1997, that additional investigations would be required. The ISRT notified EPA in July 1997 that they had fulfilled their obligations under the Consent Decree and did not believe that more investigations were required or necessary. In the fall of 1998, EPA and the ISRT came to agreement that the ISRT would perform additional investigations, entitled the Final GSIP, and submit the investigation data to EPA. Between 1999 and 2004, the ISRT implemented the Final GSIP investigation and provided the subsequent data to EPA through various submittals between 2001 and 2004.

Institutional Controls

In 1995 EPA established a working group consisting of representatives of the EPA, MADEP, land owners, and the ISRT to establish institutional controls for the site. The group proposed draft institutional controls, which are currently being finalized by EPA and MADEP to be consistent with the Massachusetts Contingency Plan (MCP) Activity and Use Limitations (AULs) format.

The institutional controls include restrictions on future use and activities allowed for portions of the Industri-plex Site based on four defined classes of land: Class A, Class B, Class C, and Class D. These classes are defined as follows:

- Class A land is defined as “unrestricted” land. This class includes parcels where contamination is not expected to be present. Some of this land may have been included in the site only as part of the original regulatory settlement with the land owner.
- Class B land includes properties where localized areas may exceed MADEP’s MCP S1 numeric standards (but the overall MCP standard is not violated), hide residues may be present, and/or data may not be available for soils at depth. Adjoining parcels may be contaminated.

- Class C land includes parcels that are contaminated above the Consent Decree Soil Action Levels. These areas are covered with either an engineered cap or approved equivalent cover.
- Class D land includes the parcels comprising the hide piles.

Figure 1-5 illustrates the general boundaries of each land class at the site. The institutional controls documents are expected to be finalized in 2005.

Multiple Source Groundwater Response Plan

In 1997, EPA prepared a Preliminary MSGRP Report (HNUS, 1997) based on existing analytical data. The purpose of the report was to compile information obtained from previous study area investigations, state enforcement files, and other data bases to identify potential contamination sources that may contribute to surface water, sediment, or groundwater contamination at or adjacent to the Industri-plex Site or to contamination off site, and to recommend areas for further study.

In 1998, EPA prepared a historical aerial photographic analysis of the Industri-plex Site and study area (EPA, 1998). In 1999, EPA evaluated the preliminary surface water and sediment data collected under the Wells G&H Aberjona River Study and the Industri-plex MSGRP and GSIP studies. Based on the preliminary data from these studies, EPA decided to combine the Wells G&H Aberjona River Study with the Industri-plex MSGRP study to form one comprehensive RI/FS for the entire river system.

Following the decision to merge the study areas, EPA prepared a historical aerial photographic analysis of the Aberjona River Study Area (EPA, 2002) and also reviewed previous Wells G&H historical aerial photographic analyses. To address potential source areas in the area south of I-95, TtNUS prepared the Preliminary MSGRP Supplemental Report – Southern Area (TtNUS, 2003). As with the 1997 MSGRP report, the purpose of this report was to compile information obtained from previous study area investigations, state enforcement files, and other data bases to identify other potential contamination sources and historical activities that may impact the surface water and sediment quality of the Aberjona River south of I-95.

The comprehensive MSGRP RI/FS environmental sampling program was conducted between July 2000 and February 2003. Surface water, sediment, and groundwater data were collected during this investigation to fill significant data gaps in the Wells G&H Aberjona River Study and the Industri-plex GSIP, as well as evaluate other potential contamination sources within the MSGRP RI Study Area. The Wells G&H Aberjona River Study investigations, conducted prior to the merging of the two studies are incorporated into this MSGRP RI and are detailed in Section 2.2.1 of this report. The comprehensive MSGRP RI/FS investigations conducted after the merger of these two studies are detailed in Sections 2.2.2 and 2.2.3 of this report.

Prospective Purchaser Agreements

Since 1996, EPA has entered into Prospective Purchaser Agreements (PPAs) with purchasers of five different parcels on the Industri-plex Site to protect the purchasers from Superfund liability related to the existing environmental conditions. The PPAs have allowed the property transfer and establishment of active businesses on two previously developed parcels and have facilitated the purchase and development of approximately 115 previously undeveloped acres of the site. The new developments on the site include the 36-acre Anderson Regional Transportation Center that opened in spring 2001, a 30-acre retail development anchored by a Target Store that opened in October 2000, and a 50-acre multi-use parcel that includes a commercial office park, hotel, and restaurant. Office buildings and a Marriott Residence Inn have been constructed on this multi-use parcel. In addition, a new I-93 interchange was completed in November 2000, providing improved access to these redeveloped areas.

1.3.3.2 Southern Study Area

The following information was summarized from the Industri-plex Site Preliminary MSGRP Supplemental Report, Southern Area (TtNUS, 2003).

The Wells G&H Site covers approximately 330 acres in Woburn, Massachusetts (see Figure 1-1). Contamination of the two municipal wells, installed in 1964 and 1967, was discovered in 1979. The groundwater was contaminated with volatile organic compounds (VOCs), including trichloroethene (TCE) and tetrachloroethene (PCE) and, as a result, the wells were shut down. Contaminants found in site soils included polynuclear aromatic

hydrocarbons (PAHs), polychlorinated biphenyl compounds (PCBs), VOCs, and pesticides. Aberjona River sediments were found to be contaminated with heavy metals, including arsenic, chromium, mercury, and zinc, and some PAHs.

A ROD for the Wells G&H Superfund Site was signed in September 1989. The ROD specified a remedy, considered Operable Unit 1 (OU-1), and designated two other operable units. The second operable unit (OU-2) is referred to as the Central Area Study, while the third operable unit (OU-3) is referred to as the Aberjona River Study. Each of the operable units is described below to provide a brief history of the cleanup and enforcement actions associated with the Wells G&H Site in the Southern Study Area.

The OU-1 remedy in the 1989 ROD required the cleanup of groundwater contaminated principally with VOCs and/or soil remediation at five identified source area properties owned by the W. R. Grace Company, Unifirst Corporation, the Olympia Nominee Trust, Wildwood Conservation Corporation, and New England Plastics (see Figure 1-6). The Consent Decree was entered in 1991, with four of the five property owners, to clean up their soil and groundwater contamination. The fifth property owner, Olympia Nominee Trust, did not participate in the Consent Decree but continued negotiations with EPA for the cleanup of their property. In the past 2 years, EPA has entered into two Administrative Orders by Consent with Olympia Nominee Trust: in 2003, to remove soils contaminated with PAHs, PCBs, and TCE from their property; and in 2004, to treat soils contaminated with TCE from the property's former drum disposal area.

The four source area property owners that signed the Consent Decree have participated in the OU-1 remedial action to date. Soils contaminated primarily with VOCs have been excavated and treated on-site and/or transported off-site for disposal. Soil vapor extraction was used to treat the VOCs that remained in the soil. Separate treatment plants have been constructed on three of the source area properties to pump and treat contaminated groundwater. Groundwater pump and treat systems at two of the source area properties have been operating since 1992; both systems use carbon adsorption for treatment of the VOC-contaminated groundwater. The system at a third source area, in operation since 1998, includes air sparging, soil vapor extraction, groundwater extraction and treatment using air stripping and carbon adsorption. Contaminated soils were removed from the fourth property

and air sparging and vacuum extraction systems were used between February 1998 and June 1999.

The ROD and Consent Decree also required that further investigations be conducted for the Central Area, or OU-2. The Central Area, as defined in the Wells G&H ROD, includes the entire Wells G&H Site, with the exception of the five source area properties and the Aberjona River, its tributaries, and the sediment and associated wetlands on the east side of the River (see Figure 1-6). The Central Area has been segregated into two investigations: the Central Area and the Southwest Properties. Three of the five Potentially Responsible Parties (PRPs) have participated in an investigation of the Central Area (OU-2) and its aquifer. The Southwest Properties investigation is being performed by one of the PRPs and is focused on three commercial properties located in the southwest corner of the site along Salem Street.

A Phase 1A RI report was completed in 1994 for the Central Area and Southwest Properties, but due to data gaps, risk assessments were not completed. Additional OU-2 remedial investigation and data collection activities to support a risk assessment for the Southwest Properties began in the fall of 2002. In March 2004, EPA completed a baseline risk assessment for the Southwest Properties. Additional data collection efforts are necessary to complete a baseline risk assessment for the Central Area.

EPA is responsible for the OU-3 Aberjona River Study for the Wells G&H Site (see Figure 1-6). The Aberjona River Study was designed to investigate the nature and extent of contamination in the Aberjona River sediments as well as evaluate potential human health and ecological risks from contaminants in the river south of I-95. EPA and the U.S. Fish and Wildlife Service (USFWS) collected surface water, sediment, and biota samples in 1995. Supplemental field activities, focused on sediment sampling, were conducted in 1997, 2000, 2001, and 2002. These studies concluded that the river and its sediments in this study area are contaminated with metals, including arsenic, chromium, and lead, similar to those related to the Industri-plex Site. This information lead to EPA's decision in the spring of 2002 to combine the Aberjona River Study with the Industri-plex MSGRP investigations; thus resulting in the inclusion of the entire river and its associated sediments and wetlands in the MSGRP RI. Baseline human health and ecological risk assessments for the Aberjona River Study were completed in 2003. Risk assessments for the Industri-plex Site have also been completed. Consistent with the

expansion of the MSGRP RI Study Area to include the entire river, both risk assessments are summarized in Section 6 (human health) and Section 7 (ecological).

2.0 FIELD INVESTIGATIONS

Numerous investigations have been undertaken by EPA and the Industri-plex Site settling defendants (under the auspices of the ISRT) to fulfill the requirements of the RODs and CDs for the Industri-plex and Wells G&H Superfund Sites to assess contamination and contaminant migration throughout the MSGRP RI Study Area. The investigations were conducted over a period of more than 10 years by various parties including the ISRT's contractors; EPA; EPA's contractors; and the U.S. Fish and Wildlife Service (USFWS).

The information and analytical data obtained during these studies were the predominant source of information used in preparing this MSGRP RI. The most recent data, collected during the final phases of investigations by the ISRT and EPA, were used quantitatively for evaluation of nature and extent of contamination, analysis of contaminant trends, interpretations of contaminant fate and transport mechanisms, and assessment of human health and ecological risks. The analytical data from these recent investigations were validated in accordance with EPA Region 1 data validation guidelines (EPA, 1996). Some of the data from earlier phases of the investigations were used only qualitatively and for comparability purposes due to the time-frame when the data were collected and due to the changed site conditions since the data were generated. Sections 2.1 and 2.2 summarize the investigations conducted in support of this MSGRP RI, and describe how the data were evaluated and used in development of the MSGRP RI.

In addition to these investigations, numerous studies have been conducted outside the Industri-plex Site and Wells G&H Site ROD processes, to investigate contamination in the area of the Industri-plex Site and throughout the Aberjona River. Many of these studies provided background and supplemental technical information for this RI, but were not used quantitatively to assess contamination, contaminant migration, or risk. Relevant studies used to support the RI are identified and briefly described in Section 2.3.

For the purposes of the baseline ecological risk assessment, the Aberjona River Study Area (the Southern Study Area) was divided into six reaches (1 through 6) defined based on similarity of habitat, species, and accessibility. For purposes of continuity, the same reaches were used in the human health risk assessment for the Southern Study Area and will be used as applicable throughout this MSGRP RI, with the addition of Reach 0 to define the Northern Study Area. The

reach designations are used in the figures and tables in this section to help orient the reader. The study area reaches are shown on Figure 2-1. See Section 2.2.1. for additional discussion of the characteristics of each reach.

Because the investigations used in preparing this RI were conducted over many years, by numerous parties, to meet varied objectives, several different nomenclatures were used to identify environmental samples and sample locations. In some cases, the same or similar identifiers were used by multiple investigators to describe different locations or samples. To minimize the confusion created by similar names, TtNUS modified sample location identifiers as needed to make all identifiers unique. In most cases this was accomplished by adding a suffix at the end of the location name, indicating the investigator (i.e. -TT for TtNUS, -FW for Foster Wheeler, and -IP for the ISRT).

2.1 Groundwater and Surface Water Investigation Plan (GSIP)

The GSIP investigations were conducted by the ISRT between 1990 and 2004 to fulfill the obligations of the settling parties under the Industri-plex ROD and CD. The overall objectives of the GSIP were to evaluate the potential for off-site migration of metals through surface water and to provide site-specific information that could be incorporated into the MSGRP RI (Roux, 1989) regarding the nature and extent of groundwater, sediment, and surface water contamination in the Industri-plex study area. Specific objectives of the GSIP were divided into four areas as follows:

1) Groundwater

- Evaluate onsite and offsite conditions.
- Identify and characterize possible sources areas.
- Define upgradient aquifer conditions influencing groundwater quality in the portion of the aquifer investigated during the initial RI for the Industri-plex Site (Woburn Environmental Studies Phase I Report, April 1983, prepared for Stauffer Chemical Company by Roux Associates. Also referred to as the Stauffer RI report).

2) Surface Water and Sediment

- Evaluate the extent and characteristics of metals and organics in the surface drainage system on the Industri-plex Site and surrounding upgradient and down-gradient areas within the Industri-plex study area.

3) Metals Mobility

- Identify the factors that govern the mobility of arsenic, chromium, lead, and mercury at the Industri-plex Site.

4) Human Health and Ecological Risk Evaluation

- Determine the extent to which surface water and groundwater contamination from the Industri-plex Site may affect human health and the environment.

The GSIP investigations were completed in three major phases, plus supplemental investigations. The first two phases of investigations were completed by the ISRT between 1990 and 1992. These investigations were documented in the Ground-Water/Surface-Water Investigation Plan Phase 1 Remedial Investigation Final Report (Roux, 1991) and the Ground-Water/Surface-Water Investigation Plan Phase 2 Remedial Investigation Draft Report (Roux, 1992). These reports are commonly referred to as the GSIP Phase 1 Report and GSIP Phase 2 Report.

After review of the GSIP Phase 1 and Phase 2 reports, EPA concluded that the investigations did not fully characterize the hydrogeology and contamination distribution and therefore did not fulfill the requirements of the GSIP stipulated in the ROD and CD. EPA requested that ISRT conduct additional investigations to fill the identified data gaps.

The ISRT undertook two investigations to supplement the GSIP Phase 1 and 2 data: the Supplemental Site Investigation (1996-1997) (SSI) and the Benzene and Toluene Source Area Investigation (1998). These two investigations were conducted by the ISRT to develop a more comprehensive understanding of site conditions. However, the SSI was conducted voluntarily by the ISRT, outside of the GSIP process (i.e. without EPA approval). Although EPA

acknowledged the work conducted and provided comments on the SSI report, EPA did not accept the ISRT's conclusions based on the limited data provided (EPA, 1998a).

In 1998, EPA and the ISRT agreed that the ISRT would conduct a final phase of investigation and to fill remaining GSIP data gaps and submit the investigation data to EPA to complete their obligations for the GSIP (EPA, 1998b). This final phase of investigation is referred to as the Final GSIP Scope of Work (SOW). The Final GSIP SOW investigations were documented in the Final GSIP Scope of Work Draft Report, Volumes 1 through 4, issued between March 2002 and February 2003 by Roux Associates, Inc.

In 2004, the ISRT conducted an additional, voluntary sub-slab soil gas investigation at the request of EPA, to support the baseline HHRA for the site.

This section provides a summary of each of the ISRT GSIP and supplemental field investigations. The data and findings relevant to this RI are discussed in subsequent sections of this report and are included in the appendices as appropriate. The GSIP reports will become part of the Administrative Record for the Site and are currently available in the information repository at the EPA Region 1 Records Center in Boston, Massachusetts.

2.1.1 GSIP Phase 1 Investigations

The information presented in this section was summarized from Ground-Water/Surface-Water Investigation Plan Phase 1 Remedial Investigation Final Report (Roux, 1991) and the Work Plan for the Ground-Water/Surface-Water Investigation (Roux, 1989 – also referred to as the GSIP RI Work Plan). Refer to these documents for additional details of the investigation. The data and conclusions of the Phase 1 investigation will be evaluated and used qualitatively in this RI to provide perspective on site conditions in 1990 and 1991 and changes in contamination over time. Because of the availability of more recent comprehensive data, the Phase 1 investigation results will not be used in the quantitative evaluation of the nature and extent of contamination; however, the geologic and hydrogeologic data from this investigation will be used to help evaluate the data collected in subsequent investigations.

The GSIP Phase 1 field investigations were conducted between March 1990 and January 1991 by Roux Associates, Inc. (Roux); Environmental Science and Engineering, Inc. (ESE); and PTI

Environmental Services (PTI) for the ISRT. The investigations included installation of groundwater observation wells; sampling and analysis of groundwater, surface water, and sediment; and measurement of surface water and groundwater elevation and flow parameters. The GSIP Phase 1 tasks were completed in accordance with the GSIP RI Work Plan (Roux, 1989). The major components of the field investigation are identified below. For more detailed information about the investigation, refer to the GSIP RI Work Plan (Roux, 1989) and the GSIP Phase 1 Report (Roux, 1991) available in the Industri-plex Site information repository.

2.1.1.1 GSIP Phase 1 Groundwater Investigation

The GSIP Phase 1 groundwater investigation was performed to determine the nature and extent of contamination in the unconsolidated aquifer beneath the Industri-plex Site and to determine the interrelationship between groundwater, surface water, and sediment at the site. The groundwater field investigation included the tasks described below.

- Three observation wells were installed to supplement existing wells installed between 1982 and 1984 as part of the initial RI/FS for the Industri-plex Site completed by Stauffer Chemical Company. Split-spoon samples were collected at 5-foot intervals in the borehole. The samples were field screened for the presence of headspace VOCs and the soils were classified and described in boring logs.
- Two shallow piezometers were installed adjacent to the Aberjona River; data-logging instruments were installed in the piezometers to continuously measure groundwater elevations.
- Water elevations were measured in all on-site groundwater observation wells and surface water staff gauges and two shallow piezometers to facilitate evaluation of groundwater and surface water flow and the interrelation of groundwater, surface water, and sediments.
- Groundwater samples were collected from 22 new and existing observation wells and analyzed for metals including tin; volatile organic compounds (VOCs); semi-volatile organic compounds (SVOCs); pesticides/polychlorinated biphenyls (PCBs); organic mercury; organic tin; metals speciation for arsenic, lead, chromium, and

mercury; and several additional water quality parameters including temperature, pH, conductivity, dissolved oxygen (DO), total suspended solids (TSS), hardness, total organic carbon (TOC), Eh, sulfide, sulfate, iron, iron⁽⁺²⁾, calcium, chloride, phosphorous, bicarbonate, carbonate, and chemical oxygen demand (COD).

2.1.1.2 GSIP Phase 1 Surface Water and Sediment Investigation

The surface water and sediment investigation was performed to evaluate the extent and characteristics of contaminants in the site and study area drainage system and gain a better understanding of the potential for off-site migration of contaminants through surface water. The surface water and sediment field investigation included the tasks described below.

- Surface water samples were collected from 15 stations. Two samples were collected from each station, one filtered and one unfiltered. Surface water samples were analyzed for metals including tin; VOCs; SVOCs; pesticides/PCBs; metals speciation for arsenic, lead, chromium, and mercury; water quality parameters including temperature, pH, conductivity, DO, TSS, hardness, TOC, Eh, sulfide, sulfate, iron, iron⁽⁺²⁾, calcium, chloride, phosphorous, bicarbonate, carbonate, and COD. Stream flow, rate, and volume were also measured at the 15 sample locations.
- Stream sediment grab samples were collected from 17 stations and analyzed for metals including tin; VOCs; SVOCs; pesticides/PCBs; metals speciation for arsenic, lead, chromium, and mercury; pH, Eh, TOC, iron oxide, manganese oxide, total carbonate, and grain size.
- One sediment core sample was collected from a depositional area in the HBHA wetlands just south of the discharge from the HBHA Pond. The core sample was analyzed for metals, VOCs, SVOCs, pesticides/PCBs, pH, Eh, and TOC.
- Water samples were collected from two locations in each trunk sewer system passing through the site. The storm sewer samples were analyzed for the same parameters as the surface water samples. The work plan called for sampling of sediment from the sewers, but no sediment was present at any of the sample locations during the sampling period.

- Surface water drainage patterns and surface discharges were identified by field mapping/observation and evaluation of published information such as aerial photographs.

2.1.1.3 GSIP Phase 1 Metals Mobility Investigation

The metals mobility investigation was performed to determine the factors governing the mobility of arsenic, chromium, lead, and mercury in site soils and groundwater. The field investigation tasks performed to meet these objectives were carried out as components the groundwater, surface water, and stream sediment investigations described above. Specific field investigation tasks performed to support the metals mobility investigation are identified below.

- Soil split-spoon samples were collected during installation of the three new observation wells (section 2.1.1.1). The soil samples were analyzed for critical chemical and physical parameters controlling the mobility of metals. Unsaturated zone and saturated zone soil samples were analyzed for: grain size, Eh, pH, TOC, iron oxide, manganese oxide, and total carbonate.
- Samples collected during the Phase 1 groundwater, surface water, and stream sediment investigations (Sections 2.1.1.1 and 2.1.1.2) were analyzed to determine the chemical forms (valence states) of arsenic, lead, chromium, and mercury.

2.1.1.4 GSIP Phase 1 Human Health and Ecological Risk Evaluation

Data developed during the groundwater, surface water, and stream sediment investigations described above were used to evaluate potential human health and ecological risks associated with exposure to contaminants in site media. Additionally, a field survey was conducted in May 1990 to support the ecological risk assessment. The purpose of the field survey was to collect fish and benthic macroinvertebrates and to assess the habitat at each sampling station. No chemical analysis or toxicity testing were performed.

Biological data were collected at 26 biological sampling stations. Seventeen stations were located on the site near corresponding surface water monitoring stations, and the remaining nine stations were located upstream of the site to serve as reference stations. Habitat

assessment, macroinvertebrates sampling, and measurement of water quality parameters (pH, DO, temperature and conductivity) were performed at all biological stations. Fish were sampled at four stations.

Macroinvertebrate sampling was conducted using petit ponar dredges or Eckman grab samplers at locations with standing water, and using Surber samplers or D-nets at locations with flowing water. The samples were evaluated to identify the macroinvertebrates present and determine the relative percent contribution of each family level. Fish sampling was conducted using gill nets in deep water (greater than 5 feet) and a portable electroshocker in shallower waters. Fish were inspected to determine the species caught at each location. Evaluation of aquatic habitat was performed at each location using Rapid Bioassessment Protocols in accordance with EPA guidance (EPA, 1989).

2.1.2 GSIP Phase 2 Investigation

The information presented in this section was summarized from the Ground-Water/Surface-Water Investigation Plan Phase 2 Remedial Investigation Draft Report (Roux, 1992) and the Work Plan for the Ground-Water/Surface-Water Investigation Phase 2 Remedial Investigation (Roux, 1991a), also referred to as the GSIP Phase 2 Work Plan. Refer to these reports, available in the Industri-plex Site information repository, for additional information on investigation methods. The data and conclusions of the Phase 2 investigation will be evaluated and used qualitatively in this RI to provide perspective on site conditions in 1991 and 1992 and changes in contamination over time. Because of the availability of more recent comprehensive data, the Phase 2 investigation results will not be used in the quantitative evaluation of the nature and extent of contamination; however, the geologic and hydrogeologic data from this investigation will be used to help evaluate data collected in subsequent investigations.

The GSIP Phase 2 field investigations were conducted between September 1991 and May 1992 by Roux; ESE; and PTI for the ISRT. The GSIP Phase 2 tasks were completed in accordance with the GSIP Phase 2 Work Plan (Roux, 1991a). The investigation was performed to further characterize groundwater flow conditions and groundwater quality at selected areas of the site and to address data gaps identified following a review of the GSIP Phase 1 investigation data and results. The investigation was divided into four areas as described in the following sections.

2.1.2.1 GSIP Phase 2 Groundwater Investigation

The GSIP Phase 2 groundwater investigation tasks focused on characterizing groundwater quality and flow conditions in the areas of the West Hide Pile and Halls Brook Holding Area and evaluating vertical flow between the unconsolidated and bedrock aquifers. Specific tasks performed for this investigation are identified below.

West Hide Pile benzene plume investigation – Additional investigation was needed to further define the extent of benzene previously detected in an observation well (OW-31) on the eastern side of the West Hide Pile.

- Five 2-inch diameter piezometers were installed around the perimeter of the West Hide Pile. The piezometers ranged in depth from 5 to 10.4 feet below ground surface and were screened across water table. One was installed by a truck-mounted rig, the other four were hand-driven well points.
- Groundwater samples were collected from OW-31 and four of the newly installed piezometers and analyzed for VOCs and metals (the remaining piezometer was not sampled because it was dry at the time of the Phase 2 sampling).
- Water levels were measured in nine observation wells and four piezometers in the vicinity of the West Hide Pile to determine groundwater flow direction in the area.

Halls Brook Holding Area underflow evaluation – Groundwater elevation and groundwater quality data were collected to determine the potential for underflow beneath the HBHA Pond.

- Two observation well clusters were installed near two existing wells east and northeast of the HBHA Pond. Each cluster consisted of three wells screened within the unconsolidated aquifer (across water table, middle, and bottom) and one bedrock well screened in the upper bedrock immediately underlying the unconsolidated deposits.

- Continuous split-spoon samples were collected during the installation of the deepest overburden well at each location. Split-spoon soil samples were field-analyzed for the presence of VOCs using a PID.
- Groundwater samples were collected from the new and existing wells and two additional wells on the west side of the HBHA Pond. Samples were analyzed for VOCs and dissolved metals.
- Groundwater head (elevation) measurements were made in the new wells and all other existing observation wells around the HBHA during January, February, and March 1992.
- A surface water staff gauge was installed in the HBHA Pond near one of the well clusters. Surface water elevation measurements were taken at this location in March 1992 (heaving ice prevented measurement during other monitoring rounds).

Evaluation of vertical flow between aquifers – Additional data were needed to evaluate groundwater flow between the unconsolidated deposits and the crystalline bedrock beneath the site. The GSIP Phase 2 Work Plan called for installation bedrock and overburden wells in the vicinity of two existing overburden wells (OW-37 and OW-9). However, following completion of 50-foot deep bedrock boreholes at these locations, recharge into the boreholes was found to be too slow to allow packer testing or groundwater sampling. Because the bedrock was relatively impermeable at these locations, EPA agreed to discontinue the bedrock investigation at these locations (Roux, 1992). Tasks completed at these locations included:

- Two observation wells were installed in the unconsolidated aquifer (screened across water table and at bottom) near OW-9. One observation well was installed to screen the base of the unconsolidated aquifer near existing water table observation well OW-37.
- Pilot 6-inch diameter boreholes were advanced 50 feet into the bedrock near the two existing wells. These boreholes were abandoned following Massachusetts guidelines after the bedrock investigation at these locations was discontinued. One of the existing wells was also abandoned due to suspected problems with well construction.

- Groundwater samples were collected from the new observations wells and one existing well and analyzed for VOCs and metals.
- Groundwater levels were measured in the new observations wells and one existing well in January, February, and March 1992.

2.1.2.2 GSIP Phase 2 Surface Water and Sediment Investigation

The Phase 2 surface water and sediment investigation was conducted to further define the nature and extent and migration of contaminants via surface water and to determine the volume of contaminated sediment and geochemical conditions controlling the contaminant distribution in the HBHA Pond. Specific tasks performed for this investigation are identified below.

Nature and extent evaluation – Additional data were needed to better define the migration of contaminants in study area surface water and stream sediment.

- Surface water and sediment samples were collected at six new sampling stations. Surface water samples were analyzed for VOCs, SVOCs, metals (filtered and unfiltered), TSS, and TOC. In addition, several water quality parameters (pH, Eh, dissolved oxygen, temperature, and conductivity) were measured in the field at the time of sample collection. Stream sediment samples were collected at the new stations using a Ponar dredge. Sediment samples were analyzed for VOCs, SVOCs, metals, pH, Eh, grain size, TOC, sulfide, and ammonia.
- Stream flow conditions were measured at six of the Phase 1 sampling stations in order to characterize flow conditions at the time of sampling and attempt to make a correlation between this sample round and previous sample rounds conducted under the GSIP Phase 1.

Sediment volume and geochemistry investigation – Additional data were needed to determine the volume, form, and bioavailability of contaminants in the HBHA Pond. Specific tasks performed to meet these objectives are identified below.

- Sediment depth and water depth were measured at 19 locations evenly spaced throughout the HBHA Pond.
- Sediment core samples were collected from three locations in the HBHA Pond (north, central, and south) using a 4-inch diameter 6-foot long PVC sampler. Sampling was conducted from a boat using a slide hammer and PVC riser tube to manually drive the sampler to refusal (at approximately 2- to 3-feet below the sediment surface). Sediment was extruded from the core tube using a plunger. Sediment samples were analyzed for TAL metals; arsenic, chromium, and lead; benzene, toluene, ethylbenzene, and xylenes (BTEX); and TOC. In addition, six sediment core samples, representing the upper (fine) and lower (coarse) sediment layers, were analyzed for particle size distribution by wet sieving.
- Six pore water samplers were installed near the sediment sampling locations to provide data relating the chemical composition of the pore water to that of the bulk sediment. The samplers were allowed to equilibrate for a period of 4 weeks prior to withdrawing a sample. Samples were analyzed for BTEX, metals, major anions, alkalinity, Fe(II), Fe(III), sulfide, pH, Eh, dissolved organic carbon (DOC), specific conductivity, and temperature.
- Three seepage meters were installed in the HBHA Pond to evaluate groundwater flux to and from the pond. The seepage meter was allowed to equilibrate with groundwater discharge for 4 weeks without collecting water. Following equilibration, an evacuated Tedlar bag was placed on each meter and left undisturbed for 5 to 7 days. The volume of water collected from each seepage meter was used to calculate the groundwater discharge rate at that location. Except where there was insufficient sample volume for all the analyses, the water collected in the seepage meters was analyzed for arsenic species, chromium species, BTEX and geochemistry parameters including Fe(III), sulfide, DO, DOC, pH, Eh, alkalinity, and nitrogen.

2.1.2.3 GSIP Phase 2 Metals Mobility Investigation

The GSIP Phase 2 metals mobility investigation was conducted to collect data to better characterize the geochemical and physical parameters that govern metals mobility in site soil and groundwater. The major tasks are described below.

Groundwater metals speciation – Groundwater samples were collected from 18 observation wells located in three main areas of interest (East-Central Hide Pile, West Hide Pile, and South Hide Pile) and background/upgradient locations. Groundwater samples were analyzed for speciation of the metals of concern (arsenic and chromium) and parameters affecting redox chemistry (species of iron, nitrogen, and sulfide; DO; alkalinity; organic acids; pH; Eh; and DOC).

Aquifer soils metals mobility parameters – Saturated zone soils were collected from two locations at the perimeter of and near the center of the contaminant plume originating from the East Hide Pile. The samples were collected from drill cuttings from the installation of observation wells at these locations. Soil samples were analyzed for cation exchange capacity, TOC, mineralogy, bulk density, and particle size distribution.

2.1.2.4 GSIP Phase 2 Ecological Risk Investigation

The GSIP Phase 2 ecological risk assessment was needed to further evaluate the potential impacts of site contaminants of concern (COCs) on aquatic and semi-aquatic receptors in the HBHA and adjacent wetlands. Field investigation tasks conducted to support the ecological risk assessment are described below.

Sediment bioassay sampling – A sediment bioassay investigation was performed to evaluate the toxic effects of site COCs on benthic organisms in sediments affected by the site. Sediment samples were collected from depositional areas in four locations downstream of the site and two reference locations upstream of the site. The samples were submitted for bioassay toxicity testing on two types of freshwater organisms: *Chironomus tentans* and *Hyallela azteca*. Toxicity test duration for *Chironomus tentans* was 14 days; the toxicological endpoints were survival and growth. Toxicity test duration for *Hyallela azteca* was 14 days; the toxicological endpoints were survival, growth, and reproduction.

Fish sampling – Fish sampling was conducted to determine the concentrations of COCs in fish tissue to evaluate the potential hazards to the fish and any predators that feed on them. Fish were collected from HBHA Pond and from Phillips Pond, a reference location not influenced by the site. Large fish were collected using gill nets. Smaller fish were collected using minnow traps. The goal of the sampling was to collect at least five fish from each of three trophic levels (forager, bottom-feeder, and predator) from each pond. However, no foragers were recovered from HBHA Pond. Five bottom feeders (brown bullhead and white suckers) and three predators (golden shiners) were collected from HBHA Pond. Three foragers (pumpkinseed), six bottom feeders (white suckers), and six predators (golden shiners) were collected from Phillips Pond.

All fish were measured for length and weight and prepared for analysis. Small fish were analyzed whole. The fillet and offal (entrails) of the large fish were analyzed separately. The fish samples were analyzed for metals, VOCs, SVOCs, and percent lipid.

2.1.3 GSIP Supplemental Site Investigation

The information presented below was summarized from the Supplemental Site Investigation Report (Roux, Camp Dresser & McKee, ESE, Envirogen, September 1997). Refer to that report available in the Industri-plex Site information repository, for additional information on investigation methods. The data and conclusions of the Supplemental Site Investigation (SSI) will be evaluated and used qualitatively in this RI to provide perspective on site conditions in 1996 and 1997 and changes in contamination over time. Because of the availability of more recent comprehensive data, the SSI results will not be used in the quantitative evaluation of current environmental conditions in the Northern Study Area.

The SSI was undertaken by the ISRT in 1996 to further evaluate the geochemical transformations and environmental fate of site COCs in the groundwater and surface water in the Northern Study Area. The study was conducted for the ISRT by a team comprised of Roux, Camp Dresser & McKee (CDM), ESE, Envirogen. The work was conducted outside the formal GSIP process, without prior work-plan approval by EPA.

The objectives of the SSI were to evaluate current site conditions; conduct a preliminary evaluation of COC mobilization mechanisms; investigate geochemical and biological processes potentially affecting discharge of COCs to the HBHA Pond; and develop an initial groundwater

flow model to quantitatively model the hydrogeological and geochemical processes controlling COC fate and transport. The SSI was divided into five work elements. The field investigation tasks conducted for these five elements are described below.

2.1.3.1 SSI Source Areas Investigation

The source areas investigation was conducted to further evaluate arsenic mobilization at Industri-plex Site source areas, assess current geochemical conditions in source-area groundwater, and assist in calibrating the groundwater flow model being developed as part of the downgradient groundwater investigation. Field investigation tasks performed to meet these objectives are described below.

Groundwater Geochemistry Evaluation – Groundwater monitoring wells were installed and groundwater samples were collected at five locations downgradient of the West, East-Central, and South Hide Piles and the arsenic pit to assess the current geochemical conditions in source-area groundwater and to assist in calibrating the groundwater flow model.

Four of the wells were situated at the locations of previous (GSIP) monitoring wells and were screened at the same depth interval as the previous wells in order to evaluate temporal changes in the aquifer conditions at these locations. The fifth well was installed near the location of a former monitoring well.

The wells were installed using direct-push drilling methods. Groundwater samples were extracted from the screened interval using polyethylene tubing and a vacuum pump, placed into appropriate sample containers, and sent to a laboratory for chemical analysis. Samples to be sent for dissolved analyses were filtered in the field after collection. Filtered samples were analyzed for selected COCs (benzene, toluene, arsenic, chromium, calcium, copper, iron, magnesium, potassium, sodium, and zinc); arsenic species; DOC fractionation; and the following geochemical parameters: DOC, copper, zinc, sulfate, sulfide, nitrate, nitrite, ammonia, major cations, major anions, ferrous iron, and chromium species. Unfiltered samples were analyzed for copper, iron, zinc and TOC. Unfiltered samples were also analyzed in the field for pH, Eh, DO, temperature, and specific conductance.

Soil Geochemistry Evaluation – A soil/hide-material column study was performed using source area waste/soil and upgradient site groundwater to simulate the reducing conditions of site groundwater and evaluate the effect of such reducing conditions on arsenic mobilization and speciation. The test column was constructed of a 2-foot long, 2-inch diameter glass tube packed with 8 inches of hide-containing soils overlain by 10-inches of arsenic impacted soils. The column had end caps with inlet and outlet ports to allow a continuous flow of water through the column. Site groundwater was passed through the column in upflow mode at a rate similar to that of groundwater flow at the site (approximately 1 milliliter/minute or 2 feet/day).

The soil/hide materials and groundwater for the column test were collected using procedures designed to minimize changes in the in-situ biological and chemical characteristics (anaerobic bacterial population, pH, DO, and ORP) of the materials. The hide-containing soils were collected from two borings in the eastern portion of the East-Central Hide Pile using acetate-lined core samplers. The acetate cores were placed in anaerobic sample bags kept under continuous positive nitrogen pressure and cut into 2-foot lengths for shipment to the laboratory. Arsenic-impacted soils were collected from three borings in the arsenic pit area located south of the West Hide Pile. The core samples from each boring were composited to yield one sample from each boring. The composite samples were transferred to glass jars for shipment to the laboratory. Groundwater was collected from a well located upgradient of the East-Central Hide Pile using low flow groundwater pumping techniques. The well was purged until the water's ORP and DO stabilized, then the water was pumped into a nitrogen-purged carboy. All samples were protected from sunlight and temperature extremes during transport and were stored at 4°C upon arrival at the laboratory.

2.1.3.2 SSI Downgradient Groundwater Investigation

The downgradient groundwater investigation included evaluations of groundwater geochemistry and flow gradients in the area of the HBHA Pond, and the development of a preliminary flow model for the Industri-plex Site and study area. The tasks conducted for this investigation are described below.

Groundwater Geochemistry – Three micro-well clusters were installed along the east bank of the HBHA Pond and wetlands to assist in the evaluation of groundwater geochemistry downgradient of the source areas and calibration of the preliminary groundwater flow model,

and to provide groundwater for adsorption and biodegradation tests being performed as part of the HBHA Pond sediment investigation (subsection 2.1.3.3).

Each well cluster consisted of three 1-inch diameter carbon-steel wells with 10-foot well screens installed using direct-push drilling methods. In each cluster, one well was screened just above the bedrock surface, one was screened across or just below the water table, and one was screened mid-way between the other two. Well cluster MC-1 was installed at the location of a former GSIP monitoring well cluster to permit comparisons of conditions at the location over time. The other two well clusters were situated in previously unsampled areas.

Following well installation and development, groundwater samples were collected from each well, placed into appropriate sample containers, and sent to laboratories for chemical analysis. Samples to be sent for dissolved analyses were filtered in the field after collection. Filtered samples were analyzed for selected COCs (benzene, toluene, arsenic, chromium, and select metals including calcium, iron, magnesium, potassium, and sodium); and the following geochemical parameters: DOC, sulfate, sulfide, major cations, major anions, and ferrous iron. Unfiltered samples were analyzed for TOC. Unfiltered samples were also analyzed in the field for pH, Eh, DO, temperature, and specific conductance. Groundwater samples from three wells were also analyzed for arsenic species and sent to CDM's Colorado laboratory for use in batch adsorption testing of pond and wetland sediment. Groundwater from one well was also sent to ESE's Gainesville, Florida laboratory for use in biodegradation testing of pond and wetland sediment.

Groundwater Flow Gradients – Water elevation measurements were taken in the three new micro-well clusters and in stream gauges installed in the HBHA Pond and wetlands to aid in the evaluation of groundwater/surface water interactions and the direction and magnitude of vertical hydraulic gradients in the HBHA. This information was ultimately used in conjunction with previous GSIP data, to calibrate the groundwater flow model. The water level measurements were taken on May 1, 1997 during a period of relatively low precipitation.

Groundwater Modeling – The modeling effort conducted for the SSI consisted of developing a preliminary groundwater flow model to: investigate groundwater flow paths and discharge points; test the sensitivity of the model to hydrogeologic variables; and estimate the rate of groundwater discharge to the HBHA Pond to help assess the assimilative capacity of the pond.

The model was developed by CDM using its DYNFLOW modeling code and site data gathered during the SSI and previous GSIP studies. Refer to the SSI Report (Roux, et al, 1997) for additional details about the model.

2.1.3.3 SSI HBHA Pond Sediment Investigation

The HBHA Pond sediment investigation included evaluation of sediment geochemistry, adsorption capacity, and biodegradation capacity. The objective of the investigation was to evaluate the current and long-term environmental fate of site COCs as groundwater discharges into the HBHA Pond. Tasks conducted for the investigation are described below.

Sediment geochemistry – Three sediment samples were collected from two locations in the HBHA Pond to assess the current sediment geochemistry and provide sediment for batch adsorption and biodegradation testing.

Two grab samples were collected from the sampling location in the northern end of the pond: one of the fine-grained surficial sediment (“black ooze”) and one of the underlying sandy material. One sample of the fine-grained surficial sediment was collected from the sampling location in the southern end of the pond. Each sample was homogenized in the field and shipped to laboratories for analysis of selected COCs (benzene, toluene, arsenic, and chromium), geochemical parameters (TOC, hexavalent chromium, total sulfur, acid volatile sulfides, pH, Eh), and sulfur species. Samples of the fine-grained sediment from the northern location were also sent to CDM’s Colorado laboratory for batch adsorption testing and to ESE’s Gainesville, Florida laboratory for biodegradation testing. The sediment from the northern location was also analyzed by CDM for the following: arsenic- and/or chromium-containing particles (by electron microscopy), and 16 metals by X-ray fluorescence.

Adsorption Capacity – Batch adsorption tests were conducted on sediment collected from the HBHA Pond to evaluate the adsorption capacity of the pond sediment. Refer to the SSI Report (Roux, et al, 1997) for additional details about the tests.

Biodegradation Capacity – Biodegradation screening tests were conducted on sediment collected from the HBHA Pond to evaluate the potential for microflora present in the pond

sediment to biodegrade benzene and toluene in groundwater discharging to the HBHA Pond. Refer to the SSI Report (Roux, et al, 1997) for additional details about the tests.

2.1.3.4 SSI HBHA Pond Surface Water Investigation

The HBHA Pond surface water investigation included an evaluation of surface water geochemistry and determination of the residence time of surface water within the pond. The tasks conducted for the investigation are described below.

Surface water geochemistry – Surface water samples were collected from the HBHA Pond and Halls Brook to assess the geochemistry of the pond surface water and to evaluate the attenuation of groundwater COCs as groundwater discharges upward through pond sediment.

Surface water samples were collected from three depth horizons (shallow, intermediate, and deep) at two locations in the HBHA Pond and from one depth at a point in Halls Brook just upstream of its outlet into the HBHA Pond. Two samples, one filtered and one unfiltered, from each location/depth were submitted for analysis for selected COCs (benzene, toluene, arsenic, chromium, calcium, iron, magnesium, potassium, and sodium) and geochemical parameters (sulfate, sulfide, major cations, major anions, ferrous iron). The filtered samples were also analyzed for DOC and the unfiltered samples for TOC. All samples were analyzed in the field for pH, Eh, DO, temperature, and specific conductance.

Surface water residence time – A dye study was performed to determine the residence time of surface water in the HBHA Pond in order to evaluate how long COCs discharged from site groundwater may remain in the pond. Rhodamine dye was added to Halls Brook, just upstream of its outlet into the pond and a portable rhodamine dye detector was placed at the outlet of the HBHA wetland at Mishawum Road to measure the Gaussian distribution of the dye as it flowed out of the wetland into the Aberjona River. GSIP stream flow data (Roux, 1991) were used to determine the fraction of total travel time that represented retention in the HBHA Pond.

2.1.3.5 SSI HBHA Wetland Investigation

The HBHA wetland investigation included evaluations of surface water and sediment geochemistry, the adsorption and biodegradation capacities of wetland sediment, and the residence time of surface water within the wetlands.

Surface water geochemistry – Surface water samples were collected from the HBHA wetland and Aberjona River to assess the geochemistry of the wetland surface water and to evaluate the attenuation of groundwater COCs in the HBHA Pond and wetlands.

Surface water samples were collected from a single depth horizon at two locations in the HBHA wetlands and one location in the Aberjona River just downstream of the Mishawum Road culvert. Two samples, one filtered and one unfiltered, from each location were submitted for analysis for selected COCs (benzene, toluene, arsenic, chromium, calcium, iron, magnesium, potassium, and sodium) and geochemical parameters (sulfate, sulfide, major cations, major anions, ferrous iron). The filtered samples were also analyzed for DOC and the unfiltered samples for TOC. All samples were analyzed in the field for pH, Eh, DO, temperature, and specific conductance.

Sediment geochemistry – One sediment core was collected from each of two locations in the HBHA wetlands to assess the current geochemical conditions in the wetland sediment, to evaluate vertical differences in sediment geochemistry, and to provide sediment for batch adsorption and biodegradation testing.

Each core was 2.5 feet long and was divided into 0.5-foot subsamples. Each subsample was homogenized in the field and shipped to laboratories for analysis of COCs (benzene, toluene, arsenic, and chromium) and geochemical parameters (TOC, hexavalent chromium, total sulfur, acid volatile sulfides, pH, Eh). The samples were also analyzed for sulfur speciation and were sent to CDM's Colorado laboratory for batch adsorption testing, electron microscopy analysis, and XRF analysis. Fine grained sediment (the upper 1.5 feet) from one location was composited and sent to ESE's Gainesville, Florida laboratory for biodegradation testing.

Adsorption Capacity – Batch adsorption tests were conducted on sediment collected from the top 0.5 feet of one of the wetland sediment cores to evaluate the adsorption capacity of the

wetland sediment. Refer to the SSI Report (Roux, et al, 1997) for additional details about the tests.

Biodegradation Capacity – Biodegradation screening tests were conducted on sediment collected from one HBHA wetland location to evaluate the potential for microflora present in the wetland sediment to biodegrade benzene and toluene in groundwater. Refer to the SSI Report (Roux, et al, 1997) for additional details about the tests.

Surface water residence time – The residence time of surface water in the HBHA wetlands was estimated using the dye study described above in section 2.1.3.5. GSIP stream flow data (Roux, 1991) were used to determine the fraction of total travel time that represented retention in the HBHA wetlands.

2.1.4 GSIP 1997 Benzene and Toluene Source Area Investigation

The information presented below was summarized from the Benzene and Toluene Source Area Investigation (Roux, January 1998) (see Appendix 2B-1). The investigation provided screening-level data regarding conditions in a small area of the site. Because of the screening-level nature of the investigation and the availability of more recent comprehensive data, the source area investigation results will not be used in the quantitative evaluation of environmental conditions in the Northern Study Area. The data and conclusions of the investigation will be evaluated and used qualitatively in this RI to provide perspective on changes in source area contamination over time.

The Benzene and Toluene Source Area Investigation was conducted during November and December 1997 as a fast-track study to investigate a potential continuing source of benzene between the East Central Hide Pile and the Boston Edison right-of-way (centered south of Atlantic Avenue) and toluene in the vicinity of the intersection of Commerce Way and Atlantic Avenue, where redevelopment and road construction activities were scheduled to begin in early 1998. The investigation was conducted to generate screening-level data that could be used to make prompt decisions about the need for response actions in the area.

The investigation was focused around the location of former monitoring well OW-16, installed in 1983 and abandoned in 1993, and micro-well GW-3, installed in the same area during the SSI in

1996. OW-16 (screened from 15- to 35-feet below ground surface (bgs)) consistently exhibited toluene concentrations of 30,000 to 35,000 ug/L from 1983 to 1993; however, GW-3 (sample depth 23 feet bgs) contained only 4 ug/L toluene during the 1996/1997 sampling. According to Roux (1998), benzene had never been detected in OW-16 or GW-3, but it was included in the investigation based on EPA's assertion that it had been detected in groundwater entering a test pit excavated during a previous investigation. The Benzene and Toluene Source Area Investigation was intended to further investigate the area to determine whether a continuing source was present that could be addressed during redevelopment of the area.

The Benzene and Toluene Source Area Investigation included a soil gas survey, geophysical survey, soil sampling, groundwater sampling, and test pit excavations. The field investigation tasks are described below.

Soil gas survey – A soil gas survey was conducted in November 1997. Soil gas samples were collected at 39 locations and analyzed in the field for benzene and toluene using a gas chromatograph (GC). The sample locations were situated based on a 50-foot grid spacing in a 300-foot by 300-foot area; the locations were modified as necessary to accommodate surface features. The soil gas samples were collected from a depth of 2 to 4 feet bgs.

Geophysical survey – A geophysical survey was conducted in November 1997 using magnometry and ground-penetrating radar (GPR). The magnometer survey was performed across the entire accessible portion of the 300-foot by 300-foot area investigated during the soil gas survey plus a contiguous area extending approximately 250 feet south. The purpose of the magnometer survey was to identify potential ferromagnetic anomalies. The GPR survey was then performed to further investigate any anomalies identified by the magnometer. The GPR survey was conducted in a similar but slightly smaller area than the magnometer survey because of additional access limitations of the GPR.

Soil sampling – Soil boring and sampling was conducted in November 1997 using direct-push drilling. Samples were collected from 25 borings within the source area investigation sampling grid (the approximately 300-foot by 550-foot area investigated in the geophysical survey). (Four additional borings were advanced, but were sampled only for groundwater.) The boring locations were selected to provide adequate overall coverage of the potential source area, as well as to investigate specific areas of concern including: the area of a former excavation on the

west bank of the Aberjona River where toluene had been detected in groundwater; the area of former monitoring well OW-16; an area identified for construction of a storm water retention basin during planned road construction activities; and several areas where the magnetic anomalies were identified during the geophysical survey.

Soil samples were collected continuously from the ground surface down to the water table or point of boring refusal at each location. In total, 42 samples were collected for field analysis. The soil samples were collected in a core sampler with an acetate liner. When retrieved, the samplers were sliced open and a soil sample was obtained from the center portion of each sampler. The samples were analyzed in the field for benzene and toluene using ENSYS Enviroguard™ BTEX-in-soil field test kits. Five soil samples were sent to a laboratory for confirmatory analysis of BTEX compounds using EPA methods 8240 and 8020.

Groundwater sampling – Shallow groundwater samples were collected from approximately 2 feet below the water table at all the soil boring locations discussed above, except five locations where refusal was encountered prior to reaching the water table. Additionally, deeper groundwater samples (5 to 20 feet below the water table) were collected at three of the soil boring locations and four new locations. In total, 29 groundwater samples were collected for analysis.

All groundwater samples were analyzed in the field for benzene and toluene using a GC. In addition, three samples were sent to a laboratory for confirmatory analysis of BTEX compounds using EPA method 8020.

Test pit excavations – Four test pits were excavated at locations where the geophysical survey indicated the potential presence of cylindrical objects such as drums or underground storage tanks (USTs). No samples were collected from the excavations.

2.1.5 Final GSIP SOW Investigation

The GSIP Final SOW Investigation was conducted by the ISRT to more fully characterize the hydrogeology, contaminant distribution, and contaminant fate and transport mechanisms in the area of the Industri-plex Site. The Final SOW was divided into five investigations addressing the major areas of focus: additional investigations to supplement the previous Source Area

Investigation, the Groundwater and Soil Investigation, the Surface Water Monitoring Investigation, the Downgradient Transport Investigation; and the Ecological Risk Investigation. The Final SOW field investigations were performed by the ISRT's contractors between June 1999 and December 2002. The field investigations are described below. Sample log sheets from the Final GSIP SOW investigations are included in Appendix 2A, arranged by media. The Final GSIP SOW investigation data reports are available in their entirety at the EPA information repository in Boston, Massachusetts. Excerpts from the Final GSIP SOW data reports are provided in Appendix 2B.

The data obtained during the GSIP Final SOW investigation will be used in the quantitative evaluation of current environmental conditions in the Northern RI site study area. The data will be used, along with data collected during the MSGRP investigations, to determine the nature and extent of contamination, identify the mechanisms affecting the fate and transport of site contaminants, and assess the potential risks to humans and the environment from exposure to site contaminants. All sample analytical data from the GSIP Final SOW investigations were validated in accordance with EPA Region 1 data validation guidelines (EPA, 1996).

2.1.5.1 Final GSIP SOW Source Area Investigation

The information presented in this section was summarized from the Interim Letter Report Final GSIP SOW Source Area Investigation, Roux Associates, October 31, 2001 (Appendix 2B-2); Interim Letter Report Final GSIP SOW Source Area Investigation, Roux Associates, May 24, 2002 (Appendix 2B-3); the Final GSIP Scope of Work Source Area Investigation Final Report, Roux Associates, February 25, 2003 (Appendix 2B-4); and the Source Area Investigation Work Plan, Roux Associates, October 8, 1998 and amended April 8, 2000. These documents were prepared by Roux on behalf of the ISRT and are available in the Industri-plex Site information repository.

The source area field investigation was conducted by Roux, on behalf of the ISRT between August 2001 and December 2002. The objective of the investigation was to further evaluate the potential for residual sources of benzene and/or toluene in the Northern Study Area. The initial focus of the source area investigation was on two suspected source areas: the West Hide Pile and the Vining Property. After the investigation was initiated, three additional potential source areas along Atlantic Avenue and the Boston Edison Company Right of Way (BECO ROW) were

included in the investigation at the request of EPA. The potential source areas investigated in this study are described below and shown on Figure 2-2.

- West Hide Pile study area – an approximately 200-foot by 300-foot area encompassing most of the east side of the West Hide Pile. This area is a suspected source of benzene detected in groundwater beneath the eastern flank of the West Hide Pile during investigations in 1990 and 1991.
- Vining property study area – an irregularly shaped, approximately 250,000-square foot area on the south side of Atlantic Avenue comprising the Vining (former C. Bain) and Graphique de France properties on Atlantic Avenue and the rear portion of the Pacer property on Commerce Way. This area is a suspected source of benzene and toluene detected in groundwater south of Atlantic Avenue in 1982 and 1983.
- Sacco study area – an approximately 150-foot by 400-foot area encompassing the southern third of the Sacco property at 41 Atlantic Avenue. This area is a suspected source of benzene and toluene detected in groundwater north of Atlantic Avenue in 1982 and 1983.
- ABC Roofing study area – an approximately 200-foot by 350-foot area comprising the storage yard used by ABC Roofing Company at 110 Commerce Way and a contiguous area of the BECO ROW. This area is either a suspected source of benzene and toluene contamination or a downgradient receptor of contaminated groundwater potentially originating from the South Hide Pile or other potential upgradient sources such as the East Central Hide Pile detected during previous investigations.
- BECO ROW Former Digital study area – an irregularly shaped, approximately 120,000 square-foot area including the parking lot at the northern end of the former Digital facility and an adjacent area of the BECO ROW. This area is either a suspected source of benzene and toluene contamination or a downgradient receptor of contaminated groundwater potentially originating from the BECO ROW.

The field investigation consisted of four tasks: soil gas sampling, geophysical surveys, soil sampling, and groundwater sampling. These tasks are described below.

Soil Gas Survey

Soil gas surveys were conducted in the Vining and West Hide Pile study areas in August 2001 and the three additional study areas in May 2002 to investigate the presence of benzene and toluene in soil gas. The work was performed by Pine and Swallow Associates, Inc., with oversight by Roux.

Soil gas samples were collected in each area on a 50-foot grid spacing, modified as necessary for surface features such as wetlands and buildings (see Appendix 2B-2 and Appendix 2B-3). The samples were collected from half-inch hollow steel probes driven to the desired depth with a hydraulic hammer and then connected to a vacuum pump to purge the system and collect the sample. Soil gas samples were generally collected from a depth of 2 to 3 feet bgs and analyzed in the field using a portable gas chromatograph (GC). At some locations, the soil gas samples were collected from shallower than 2 feet. After completion of sampling, the probes were removed and the probe holes were filled with grout. See the interim letter reports dated October 31, 2001 and May 24, 2002 (Appendix 2B-2 and 2B-3) for additional details of the sampling and analytical methods (Roux, 2001; Roux 2002b).

Geophysical Surveys

Geophysical surveys were conducted at the Vining property and West Hide Pile study areas in August 2001 and the three additional study areas in April and May 2002 to locate subsurface metallic objects such as underground storage tanks or buried drums that may be sources of groundwater contamination. The surveys were performed by Geophysics GPR International Inc., with oversight by Roux. Three geophysical methods were used: magnetic (gradiometric), metal detection (EM61), and ground penetrating radar (GPR).

Survey grids were established in the each of the study areas using a GPS system. At the Vining and West Hide Pile study areas, the magnetic and EM61 surveys were performed, followed by the GPR survey. Only EM61 and GPR surveys were conducted at the three additional properties. The following paragraphs briefly summarize the geophysical survey.

Magnetic survey readings (Vining and West Hide Pile study areas only) were taken at 5-foot intervals, along grid lines spaced 5 feet apart. EM61 survey readings were collected at 0.65-foot intervals along grid lines spaced 5 feet apart at the Vining and West Hide Pile study areas, at 3-foot intervals along grid lines spaced 3 feet apart at the Sacco and ABC study areas, and at 3-foot intervals along grid lines spaced 5 feet apart at the Former Digital study area. Geophysical survey grids are shown in Appendix 2B-2 and Appendix 2B-3.

The data collected during the magnetic and EM61 surveys were analyzed for anomalous responses that could indicate the presence of buried metal objects. GPR surveys were then conducted in the locations of any observed anomalies to further investigate potential sources. In each survey area, continuous GPR scans were made at 5-foot intervals, along grid lines spaced 5 feet apart. Closer spaced scans were made in selected areas of interest. See the interim letter reports dated October 31, 2001 and May 24, 2002 for additional details of the survey methods (Roux, 2001; Roux 2002b).

Soil and Groundwater Sampling

Soil and groundwater sampling was conducted at the Vining property and West Hide Pile study areas between December 2 and December 19, 2002 to further investigate potential source areas. Soil and groundwater samples were collected from 17 boring locations on the Vining property study area and two boring locations at the West Hide Pile study area (stations RX-1 through RX-19) selected based on the findings of the soil gas and geophysical surveys and the results of previous GSIP investigations. The sample locations are shown on Figures 2-3a (soil) and 2-4 (groundwater).

Soil samples were collected continuously from the ground surface down to the water table using direct-push drilling and sampling methods. Samples were collected in 5-foot long, 2-inch diameter acetate liners. The recovered soil cores were divided into 2.5-foot sections, screened for VOCs using a photo-ionization detector (PID), and logged. A soil sample was collected from each 2.5-foot interval using a pre-cleaned syringe, which was temporarily capped to prevent volatilization. After all unsaturated zone samples were collected and screened, the soil sample from the depth interval with the highest PID reading or, if no positive PID readings were observed, the interval immediately above the water table was immersed in methanol in a

sample vial and sent to a laboratory for analysis of benzene and toluene. See Table 2-1 for soil sample locations, depths, and analytical methods.

After groundwater was encountered, the soil boring was advanced to a depth of 15 feet (or 13 feet at the two West Hide Pile borings) and a temporary well, with a 1-inch-diameter, 5-foot long screen was installed in the borehole. The wells typically extended 2 to 5 feet below the water table. A “shallow” groundwater sample was collected from each temporary well using EPA Region 1 low-flow sampling procedures. After the shallow groundwater sample was collected, the temporary well was removed from the boring and the boring was advanced through the saturated zone until refusal was encountered. A new temporary well, with a 1-inch-diameter, 5-foot long screen was then installed in the borehole and a “deep” groundwater sample was collected using low-flow procedures. At the two West Hide Pile study area borings an intermediate-depth sample was also collected at the approximate mid-point of the saturated zone. All groundwater samples were sent to a laboratory for analysis of benzene and toluene. See Table 2-2 for groundwater sample locations, depths, and analytical methods.

During drilling in the saturated zone, continuous soil cores were collected, screened, and logged as described for the unsaturated zone, except that samples were typically not collected for potential laboratory analysis and below the shallow well location, soil cores were screened and logged in 5-foot (instead of 2.5-foot) intervals. At one location (RX-18), a saturated soil sample was collected from the interval immediately below the water table due to elevated PID readings. This sample was sent to the laboratory for benzene and toluene analysis, like the unsaturated soil samples. See the *Final GSIP SOW Source Area Investigation Final Report* (Roux, 2003) for additional details of the soil and groundwater sampling and analytical methods.

2.1.5.2 Final GSIP SOW Groundwater and Soil Investigation

The information presented in this section was summarized from the Final GSIP Scope of Work Volume 2 Groundwater and Soil Investigation Draft Report, Part I; April 5, 2002; prepared by Roux Associates, Inc. on behalf of the ISRT and the Final GSIP Statement of Work issued by EPA on August 25, 1998. For additional details on investigation methods refer to these reports, available in the Industri-plex Site information repository.

The field work for the Final GSIP SOW Groundwater and Soil Investigation was conducted by Arcadis Geraghty and Miller, Inc. (Arcadis) and Roux Associates, on behalf of the ISRT, between September 2000 and February 2002. The work was performed in accordance with the *Groundwater and Soil Investigation Work Plan* (Roux, 1999 amended May 2000). The investigation addressed the tasks outlined in Sections 1.2.1, 2.1 and 2.2 of the Final GSIP Statement of Work (EPA, 1998b). The data generated during the field investigation were reviewed and validated by O'Brien & Gere Engineers, Inc. (OBG). OBG prepared the data tables and figures that comprise Parts II and III of the *Final GSIP Scope of Work Volume 2 Groundwater and Soil Investigation Draft Report*. This section describes the groundwater and soil investigations.

Final GSIP SOW Groundwater Investigation

The Final GSIP SOW groundwater investigation was conducted to define the current extent of the benzene, toluene, and arsenic plumes in the Industri-plex study area and to evaluate several potential source areas containing site-related COCs and organic materials that may be contributing to the mobilization of site-related metals, such as arsenic, in groundwater. The field investigation was conducted by Arcadis and Roux between September 2000 and February 2002.

The investigation was completed in two phases: a "plume delineation" phase and a "plume geochemistry" phase. The plume delineation field investigation was conducted between September 2000 and May 2001. The plume geochemistry investigation was conducted mainly in July and August 2001. Limited additional sampling supporting both phases was conducted in November 2001 and February 2002.

The plume delineation phase consisted of installing temporary wells and collecting groundwater samples from multiple depth intervals at 92 locations along 16 transects strategically located throughout the study area. Groundwater samples from this phase were analyzed for a limited suite of parameters listed in the table below.

The plume geochemistry phase consisted of installing additional wells and collecting additional groundwater samples at selected locations and depths investigated during the plume delineation phase, and analyzing the samples for a more comprehensive list of parameters

(identified in the table below). The sample locations for the geochemistry phase were selected jointly by EPA and the ISRT after reviewing preliminary analytical results from the plume delineation phase. (TtNUS collected ‘split’ samples from selected locations during this investigation on behalf of EPA. These samples were submitted for analysis of parameters in addition to those being performed by the ISRT. See Section 2.2.2.4 for details.)

**Analytical Parameters
GSIP Final SOW Groundwater Investigation**

Plume Delineation Phase	Plume Geochemistry Phase
Benzene, Toluene	TCL VOCs, TCL SVOCs
Arsenic – total and dissolved	Arsenic – total and dissolved
Arsenic species (if total arsenic is greater than 50 ug/L)	Arsenic species (if total arsenic is greater than 50 ug/L)
Chromium, Iron, Lead– total and dissolved	TAL Metals– total and dissolved
Mercury– total and dissolved	Mercury– total and dissolved
Total Suspended Solids	Total Suspended Solids
Ferrous Iron, Sulfide (field screening)	Ferrous Iron, Sulfide (field screening)
--	Nitrate, Nitrite
--	Sulfate
--	Carbonate, bicarbonate
--	Phosphate
--	Ammonia
--	Dissolved Organic Carbon

The same sample collection methods were used during both phases. Direct-push drilling methods were used to advance temporary well screens and risers (ranging from ½- inch to 1-inch diameter) to the desired sampling depths at each location. During the plume geochemistry phase, new temporary wells were installed near the location of the original well. Groundwater samples were collected using EPA Region 1 Low Flow Sampling Procedures except where site specific conditions (i.e. limited groundwater recharge or depth to water greater than 25 feet) precluded their use. In general, the groundwater was extracted using a peristaltic pump and run through a flow-through cell where field parameters (temperature, conductivity, DO, pH, ORP, turbidity) were measured. The groundwater was pumped until the field parameters stabilized and then the sample was collected. If conditions had not stabilized within the 4-hour maximum purging time stipulated in the work plan, the sample was collected and the sample was designated as “non-stabilized”; this occurred at several locations, mainly

due to an abundance of fine sands and silt in the extracted groundwater and the lack of suitable well screening materials. At locations where standard low-flow techniques could not be used because of slow groundwater recharge or depth to water greater than 25 feet, samples were collected by alternative methods selected to minimize the amount of particulate matter in the samples (e.g. filtered samples); these samples were also designated as “non-stabilized”.

The 16 transects used in the groundwater investigation were divided into five groups, based on sampling objectives. The sampling activities for each group are summarized below. Groundwater transects and sample locations are shown on Figure 2-4. A sampling summary is presented on Table 2-2.

- 1) Buried Aquifer Conditions “B” Transects – Nine transects (B1–B9), each with five to seven sample locations, were located in the area between the hide piles and the HBHA Pond to define the current vertical and horizontal extent of the contaminant plumes and evaluate aquifer conditions. Groundwater samples were generally collected from three depth intervals (shallow, intermediate, deep) within the overburden aquifer at each location during the plume delineation investigation; however fewer samples were collected at several locations due to shallow bedrock. In total, 146 samples were collected from 52 well locations during the plume delineation phase of the investigation. The samples were analyzed for the plume delineation parameters listed in the table above. Of the 143 samples collected, 23 were designated as “non-stabilized”.

During the plume geochemistry phase, 33 additional samples were collected from 21 B-transect locations and analyzed for the comprehensive suite of plume geochemistry parameters listed in the table above. Only one depth interval was sampled at most locations; two depth intervals were sampled at eight locations and all three depth intervals were sampled at two locations. Of the 33 samples collected during the plume geochemistry phase, 23 were designated as “non-stabilized”.

- 2) Boston Edison Right-of-Way Eastern “E” and Western “W” Transects – Three transects were located downgradient of the Boston Edison Company (BECO) right-of-way (ROW) to evaluate aquifer conditions associated with site-related animal hide waste materials in the ROW that were capped as part of the soil remedy. One transect (W5) with eight well locations, was located south of the western portion of the ROW and two transects (E3

and E4) with a total of seven wells were located south of the eastern portion of the ROW. At each location, groundwater samples were collected from the shallow, intermediate, and deep portions of the overburden aquifer. In total, 53 samples were collected from the BECO ROW well locations during the plume delineation investigation. The samples were analyzed for the “plume delineation” parameters listed in the table above. Of the 53 samples collected, 7 were designated as “non-stabilized”.

During the plume geochemistry phase, 10 additional samples were collected from six BECO transect locations and analyzed for the comprehensive suite of plume geochemistry parameters listed in the table above; two of these were designated as “non-stabilized”. One depth interval was sampled at three locations; two depth intervals were sampled at two locations and all three depth intervals were sampled at one locations.

- 3) HBHA Pond Buried Valley “H” Transects – Two transects (H1 and H2) with a total of 13 wells locations were situated south of the HBHA Pond to evaluate plume migration. At each location, groundwater samples were collected every 10 feet in the overburden aquifer. In total, 60 samples were collected from these transects during the plume delineation investigation, of which 7 were designated as “non-stabilized”. The samples were analyzed for the “plume delineation” parameters listed in the table above.

During the plume geochemistry phase, six additional samples were collected from three H transect locations and analyzed for the comprehensive suite of plume geochemistry parameters listed in the table above. Two depth intervals were sampled at each location. Field parameters had stabilized at all of these locations before sampling.

- 4) Former Mishawum Lake Bed “L” Transect – One transect (L2) with five well locations was located immediately downgradient of the former lake bed to evaluate potential releases from the lake bed sediments, which contain high concentrations of metals. At each location, groundwater samples were collected every 10 feet in the saturated portion of the overburden aquifer. In total, 22 samples were collected from this transect during the plume delineation investigation, of which 4 were designated as “non-stabilized”. The samples were analyzed for the “plume delineation” parameters listed in the table above.

During the plume geochemistry phase, four additional samples were collected from two L transect locations and analyzed for the comprehensive suite of plume geochemistry parameters listed in the table above. Two depth intervals were sampled at both locations. Field parameters had stabilized at all of these locations before sampling.

- 5) Potable Drinking Water Supply “P Transect – One transect with seven well locations was located just north of I-95 to evaluate potential contaminant migration into the wellhead protection area for public drinking water supply wells G and H, located south of the highway. At each location, groundwater samples were collected every 10 feet in the overburden aquifer. In total, 46 samples were collected from this transect and analyzed for the comprehensive suite of “plume geochemistry” parameters listed in the table above. Of the 46 samples, 13 were designated as “non-stabilized”.

This area was investigated in a combined plume delineation/plume geochemistry investigation conducted between April, 2001 and February, 2002. Most of the sampling was performed from April through August 2001. Limited additional samples were collected in November 2001 and February 2002 to address problems encountered during the initial investigation: In November 2001, one location (P1-03-GW-06) was re-sampled to investigate previous anomalous results for arsenic, and new temporary wells were installed at three locations (P1-01, P1-02, and P1-03) because it was believed that the original wells had not reached all the way to bedrock. A total of seven samples were collected at these new wells beginning 10 feet beyond the last samples collected (63 feet and 53 feet respectively). Because of the high volume of silt in the extracted groundwater from these wells, before collecting the three deepest samples (P1-01-GW-07 and -08, P1-02-GW-07), the well screens were filled with approximately 3 feet of silica-sand to act as a filter pack. This significantly reduced the amount of silt in the extracted groundwater. In February 2002, four samples were re-collected at three additional sample intervals at these locations (P1-01-GW-06, P1-02-GW-05 and -06) using sand-filled well screens and extended purging times to reduce the volume of suspended solids in the extracted groundwater.

Final GSIP SOW Soil Investigation

The Final GSIP SOW soil investigation was conducted to determine whether site-related contaminants exist within and adjacent to the boundaries of the former Mishawum Lake bed as a result of historical deposition before the lake was filled in. The soil investigation was conducted in May 2001 by Roux for the ISRT.

Soil borings were advanced at 20 locations (SO-1 through SO-20) using direct-push drilling methods. Soil samples were collected continuously from the ground surface to the bottom of the former lake bed (as evidenced by fine-grained soils containing remnant organic matter). The soils were described on soil boring logs. At most locations, two soil samples were collected for analysis: one from the surface and one that spanned the deeper peat/sediment layer at the bottom of the now-filled former lake bed. The surface sample was typically collected from a 0- to 1-foot depth interval. The deeper samples ranged from 1 inch thick to 4 feet thick, depending on the thickness of the lake bed sediment layer. At locations where lake bed deposits were not found (SO-4, 7, 12, 15, and 18), only a surface sample was collected. The soil samples were analyzed for TAL metals, mercury, TCL SVOCs and VOCs. Soil sample locations are shown on Figure 2-3a. A sampling summary is presented on Table 2-1.

2.1.5.3 Final GSIP SOW Surface Water Monitoring Investigation

The information presented in this section was summarized from the Final GSIP Scope of Work Volume 3 Surface Water Monitoring Draft Report; March 14, 2002; prepared by Arcadis G&M, Inc. on behalf of the ISRT, and the Final GSIP Statement of Work (EPA, 1998b). For additional details on investigation methods refer to these reports, available in the Industri-plex Site information repository.

The surface water monitoring field investigation was conducted by Arcadis, on behalf of the ISRT, between September 2000 and August 2001. The objective of the investigation was to monitor, for 1 full year, the surface water quality as it leaves the HBHA Pond and the downstream wetlands. The investigation consisted of 12 monthly sampling events. The sampling events were performed at least 48 hours after storm events with 1 inch or more rain, to ensure capturing baseflow (not storm flow) conditions.

During each sampling event, surface water samples and measurements were taken at two locations: the HBHA Pond outlet (HBHA-1) and the outlet of the HBHA wetlands at Mishawum Road (HBHA-2). See Figure 2-5a for surface water sample locations. (Note: automated sampling stations SW-4-IP and SW-9-IP were established at HBHA-1 and HBHA-2, respectively, for the Downgradient Transport Investigation discussed in Section 2.1.5.4.)

Surface water samples were collected manually using Horizontal Data Plus™ sampling bottles. The samples were collected from mid-depth of the water column, taking care to not disturb the bottom sediments while collecting the sample. The water collected in the sampling bottle was poured directly into pre-preserved sample containers provided by the laboratory or into field filtering apparatus (samples for dissolved metals analysis only). The dissolved metals samples were transferred into a clean plastic container and then filtered through a 0.45-micron filter membrane. The filtered samples were then transferred into the pre-preserved sample containers provided by the laboratory.

Samples were analyzed for BTEX compounds, total metals (arsenic, chromium, lead, iron, and mercury), dissolved metals (arsenic, chromium and lead), and total suspended solids. After collection of the samples for laboratory analysis, field parameters including dissolved oxygen, temperature, pH, and oxidation-reduction potential were measured using direct-read field instruments. A sampling summary is presented on Table 2-3. See the *Final GSIP SOW Volume 3 Surface Water Monitoring Draft Report*, (Arcadis, 2002) for additional information about sample collection and measurement of field parameters.

The elevation and velocity of flow at each sample station was measured to determine the flow conditions during each sampling event. The elevation of the surface water at each location was read directly from the staff gauges located within the stream channel. The velocity was measured using a hand-held velocity meter (Swoffer Model 2100) placed at mid-depth in the center of the stream channel at each location.

2.1.5.4 Final GSIP SOW Downgradient Transport Investigation

The information presented in this section was summarized from the Final GSIP Scope of Work Volume 4 Downgradient Transport Draft Report, Part I; April 1, 2002; prepared by Roux Associates, Inc. on behalf of the ISRT, and the Final GSIP Statement of Work issued by EPA on

August 25, 1998. For additional details on investigation methods refer to these reports, available in the Industri-plex Site information repository.

The field work for the Final GSIP SOW Downgradient Investigation was conducted by Roux, on behalf of the ISRT, between March 2000 and June 2001. The work was performed in accordance with the *Downgradient Transport (Surface water and Sediments) Investigation Work Plan* (Roux, 1999 amended May 2000). The investigation addressed the tasks outlined in Sections 2.4.1 and 2.4.2 of the Final GSIP Statement of Work (EPA, 1998b). This section describes the downgradient transport field investigations.

The primary objective of the Downgradient Transport Investigation was to determine if sediments within the HBHA are entrained in the water column and transported out of the HBHA during storm events. This objective was to be accomplished by:

- determining the hydraulic characteristics of the HBHA Pond and wetlands over a range of discharge scenarios;
- identifying the physical characteristics of HBHA sediments; and
- quantifying sediment loading, retention, and export budgets for the HBHA under normal and high-flow conditions.

The investigation was divided into two components: sediment and surface water. Each component included several tasks designed to achieve the overall objectives described above. The following sections describe the tasks performed in the sediment and surface water investigations.

Final SOW Downgradient Transport Sediment Investigation

The sediment component of the downgradient transport investigation was scoped to include five tasks:

- 1) HEC-2 Model verification and recalibration
- 2) Suspended sediment sampling and stream flow gauging
- 3) Bottom sediment volume characterization analysis

- 4) Hydraulic and sediment fate and transport analysis
- 5) Design storm analysis

However, only Tasks 2 and 3 have been performed to date. The remaining tasks have not been conducted because the ISRT and EPA had not come to agreement on the most appropriate model to use to meet the investigation objectives. The completed tasks are described below.

- Task 2 – Suspended sediment sampling and stream flow gauging – The field activities required for this task (collecting depth integrated stream sediment samples and stream flow measurements at all HBHA inflows and outflows) are a subset of the activities required for the downgradient transport surface water investigation. See that section (below) for details.
- Task 3 – Bottom sediment volume characterization analysis – Field activities for this task included two components: measuring sediment thickness and collecting sediment samples for physical properties analysis.

Sediment thickness measurements were taken at 22 locations in the HBHA Pond and three to five locations in each of the three HBHA wetland ponds (HBHA Wetland Pond 1, 2, and 3) for use in approximating the bottom sediment volume. Measurement locations were evenly distributed within each pond (see Appendix 2B-5). Measurements were obtained using a measuring tape weighted with a 1-foot-diameter perforated disk (to determine the water-sediment interface) and a length of one-inch diameter solid PVC pipe (to determine the sediment-underlying sand interface).

Samples of bottom sediment were collected from three locations in the HBHA Pond and from six locations in the HBHA wetlands and analyzed for particle size, specific gravity, and dry bulk density. The samples from the HBHA Pond were all collected from the centerline of the pond. The samples from the wetlands were collected from a variety of depositional environments including open-water pond, stream channel and stream bank. Samples were collected from 0 to 6 inches below the sediment surface using a Ponar dredge. Sample locations are shown on Appendix 2B-5.

Final SOW Downgradient Transport Surface Water Investigation

The overall objective of the surface water component of the downgradient transport investigation was to perform a complete hydraulic evaluation of the HBHA. To accomplish this objective, nine automated surface water monitoring stations were established within the HBHA and various monitoring tasks were conducted at these stations. The investigation consisted of depth-integrated stream sediment sampling, stage-response determination, surface water quality monitoring during baseflow periods and storm events, automated stage-discharge monitoring, and manual discharge measurement.

This section describes preliminary activities and these primary field investigation components of the surface water investigation.

Monitoring Station Locations and Setup - Nine surface water monitoring stations were established within the HBHA. The monitoring stations comprised all point-source inflows and outflows to the HBHA Pond and wetlands, including perennial streams such as Halls Brook and ephemeral or intermittent inflow points such as storm drain culverts. Prior to the investigation, improvements were made at each monitoring station to improve the data quality. Improvements included installing hydraulic control structures (weirs), removing debris and obstructions from channels, and pruning vegetation. The surface water monitoring stations are described in the table below and shown on Figures 2-5a and 2-5g.

Surface Water Monitoring Stations
Final GSIP SOW Downgradient Transport Surface Water Investigation

Station ID*	Location Description	Hydraulic Control	Flow Type
SW-1-IP	Halls Brook discharge into HBHA Pond	Existing box culvert	Perennial
SW-2-IP	Atlantic Avenue Drainway discharge into HBHA Pond	New concrete weir	Ephemeral
SW-3-IP	Unnamed tributary draining BECO ROW 9 and discharging into HBHA Pond	Existing culvert	Ephemeral
SW-4-IP ⁺	HBHA Pond outlet	Natural channel	Perennial
SW-5-IP	Stormwater culvert draining area west of railroad tracks, discharging into northern HBHA wetland	Existing culvert	Ephemeral

Station ID*	Location Description	Hydraulic Control	Flow Type
SW-6-IP	Stormwater culvert draining area west of railroad tracks, discharging into central HBHA wetland	Existing culvert	Ephemeral
SW-7-IP	Stormwater culvert draining area west of railroad tracks, discharging into southern HBHA wetland	New concrete weir	Ephemeral
SW-8-IP	Stormwater culvert draining area west of railroad tracks, discharging into HBHA wetland (southern end pond)	New concrete weir	Ephemeral
SW-9-IP ⁺	HBHA wetlands outlet at Mishawum Road	Existing culvert	Perennial

* "IP" suffix was added to station identifiers to distinguish stations from similarly named MSGRP surface water monitoring stations.

⁺ Stations SW-4-IP and SW-9-IP were established at Surface Water Monitoring Investigation (Section 2.1.5.3) stations HBHA-1 and HBHA-2, respectively.

Each station was equipped with an ISCO™ model 6700 programmable water sampler and an ISCO™ model 674 tipping bucket rain gauge. Each sampler contained a velocity and level sensor, a data logger to record and store hydraulic and precipitation data, and an auto sampler featuring a peristaltic pump and central compositing container for the automatic collection and storage of water samples. A staff gauge was installed at each station, and each station was surveyed to establish the base datum and cross-sectional profile of the stream channel.

An engineered sample intake was installed at each station to allow the collection of depth-integrated surface water samples using the automated samplers. The sample intake consisted of a 4-foot length of 1.5-inch diameter PVC pipe with quarter-inch slots cut on opposite sides of the pipe at one-half inch intervals over the entire length of the pipe. A suction tube sampling port was attached to the side of the pipe close to its base: at perennial stations the suction tube was located at the mid-point depth of the base-flow; at ephemeral stations the suction tube was located just above the base of the PVC pipe. The objective of this intake design was to allow water to enter the pipe from throughout the water column and mix to create a representative sample from the water column.

Following installation, the automated samplers were field-tested to evaluate their performance and accuracy. The evaluations included: comparing flow level and velocity measurements taken with the ISCO™ units to measurements taken with a Marsh-McGivney Model 2000 flow meter; comparing TSS results for samples collected using the ISCO™ samplers and engineered sample intake to those collected using a US DH-48 depth-integrating suspended sediment

sampler; and evaluating precipitation totals recorded by the tipping bucket rain gauges during three rain events.

The following conclusions were reached from the field testing:

- The flow and velocity measurements taken by the two methods were generally comparable at stations SW-1-IP, SW-2-IP, and SW-9-IP. The measurements at SW-2-IP were somewhat less comparable than the others, possibly because the low stage (approximately 1 inch of water) at this station is close to the measurement sensitivity of the Floated flow meter.
- The discharge measurements recorded by the ISCOTM unit at SW-4-IP were determined to be erroneous. Roux concluded that the Doppler velocity sensor in the unit was not functioning properly at this location due to the clarity of the water (there was insufficient suspended material in the water to reflect the radar waves). In an attempt to improve the accuracy of measurements at this station, Roux installed an aquarium air-stone just upstream of the flow sensor to create air bubbles to serve as surrogates for suspended matter. Readings taken immediately after installation of the air-stone were judged to be more accurate; however, the problem recurred and persisted throughout the study period under both base-flow and storm-event conditions.
- Stage and velocity field tests of the automated samplers were not conducted at the five remaining (ephemeral) stations because there was no flow at these stations during the field testing period.
- TSS concentrations in surface water samples collected using the two methods during a moderate (greater than 1 inch) storm event were comparable. This indicated that the engineered sample intake is an acceptable device for collecting an integrated sample from throughout the water column.
- Comparison of precipitation totals at the nine stations during three storm events identified rain gauge malfunctions at several stations during the initial storm event and at one station during subsequent events. The problems were attributed to maintenance issues such as bird droppings fouling the rain gauge. Roux conducted weekly

maintenance throughout the study period to ensure proper operation of the monitoring instruments.

For additional details on the installation, testing, and set-up of the automated sampling stations refer to the *Final GSIP Scope of Work Volume 4 Downgradient Transport Draft Report, Part I* (Roux, 2002).

Determination of Stage Response – A preliminary evaluation of stage response was conducted between July 10 and July 28, 2000 at the nine surface water monitoring stations in the HBHA. The objectives of the study were to evaluate the timing, magnitude, and duration of the response hydrographs at each station; determine flow-weighted sampling intervals and sample volumes to be used at each station during automated sampling; and to initiate development of stage discharge relationships for each station.

The automated samplers at all stations were programmed to collect discharge (stage and velocity) measurements at 2-minute intervals throughout the evaluation period. Three precipitation events occurred during the July 2000 evaluation period: July 16 (1.14 inches), July 20-22 (0.63 inches), and July 26-28 (1.37 inches). Runoff hydrographs for each storm were successfully recorded at each station. The total runoff volumes and runoff hydrographs for each storm were subsequently evaluated and used to determine the initial flow-weighted sample collection intervals and sample volumes to be used for the automated surface water sample collection/water quality monitoring investigation (see below).

The sample collection intervals and sample volumes for each station were determined based on a target total extraction volume of 3000 mL, a target number of sample intervals of 100, and the runoff hydrographs from each station for the July 20-22, 2000 storm. The final sample collection parameters were then adjusted based on the storm hydrographs to ensure that sample intervals were not too closely spaced.

Water Quality Monitoring – Surface water quality monitoring using the automated samplers was performed between August 28, 2000 and May 24, 2001. Samples were collected during three base-flow sampling events and eight storm-events. The storm event sampling was intended to capture two spring storms and two storms during each pond turn-over period (mid summer/early fall and late winter/early spring). However, because the timing of the fall turnover was unclear

due to the persistence of anoxic conditions at the base of the pond, a third fall storm sampling event was conducted to ensure that storm samples were collected after pond turn-over. A third spring storm event was added because the analytical laboratory had improperly handled a portion of the samples from the second spring storm. The table below presents the dates, type, and precipitation amounts for each of the sampling events.

Surface Water Sampling Events
Final GSIP SOW Downgradient Transport Surface Water Investigation

Date of Sampling Event	Description of Event	Total Precipitation Amount
August 28-29, 2000	Summer Baseflow	NA
September 2, 2000	Summer Storm 1	0.59 inches
September 15, 2000	Summer Storm 2	1.22 inches
October 4-5, 2000	Fall Baseflow	NA
October 5-6, 2000	Fall Storm 1	0.65 inches
October 18-19, 2000	Fall Storm 2	0.94 inches
December 17-18, 2000	Post-Turnover Storm	1.84 inches
March 21-22, 2001	Spring Storm 1	5.31 inches
March 30, 2001	Spring Storm 2A	1.76 inches
April 4-5, 2001	Spring Baseflow	NA
May 22-24, 2001	Spring Storm 2B	0.57 inches

NA – Baseflow events were conducted when no precipitation had occurred for at least 72 hours.

In general, all stations were sampled during storm events, but only the perennial stations were sampled during baseflow events due to absence of flow at the ephemeral stations. Exceptions are noted below. A sampling summary is presented on Table 2-3.

- SW-4-IP – samples were not collected during three sampling events due to recurring problems with monitoring equipment (due to clarity of water as discussed above)
- SW-8-IP – samples were not collected during the first two spring storms because the ISCOTM unit was completely submerged in floodwater during the first storm, compromising the compositing vessel. Following the storm, Roux removed the unit for maintenance and did not re-deploy it for the second storm because water levels were still high in the HBHA and additional flooding was predicted during the second storm.
- Post-turnover storm event – only SW-1-IP and SW-9-IP were sampled because the remaining ISCOTM samplers had been deactivated for the winter.

- Spring baseflow event – ephemeral/intermittent station SW-2-IP exhibited flow and was therefore sampled

Baseflow sampling was conducted when no precipitation had occurred for at least 72 hours, and when stage was visually stable at typical non-storm levels for the given monitoring period. Baseflow samples were collected by the ISCO™ units hourly over a 24-hour period. The hourly samples from each station were composited together into a single sample for each station per sampling event.

Sampling during storm events was triggered by the rainfall intensity recorded at each station. A second trigger based on stage was added after initial testing to prevent “false alarms” caused by disturbance of rain gauges by birds or other influences. Storm samples were flow-weighted samples collected at pre-determined intervals based on the flow rate and volume passing through each station. Sample intervals and volumes for each station determined based on the preliminary stage response evaluation are presented in the table below. Each sample collected was dispensed into a compositing vessel in the ISCO™ unit, to make one composite sample from each station for each sampling event. The compositing vessel at most stations had a capacity of 9000 mL to accommodate the target sample volume for a typical storm (3000 mL) and have 6000 mL additional capacity for larger storm events. Stations SW-1-IP and SW-9-IP had 18,000 mL compositing vessels to allow for collection of quality control samples. Due to the large size of the first spring storm, a second composite sample was collected at SW-9-IP to characterize conditions during the long falling limb of the storm hydrograph (Roux, 2002).

Storm Event Sampling Intervals for Auto-Samplers
Final GSIP SOW Downgradient Transport Surface Water Investigation

Sample Station	Sample Collection Interval	Sample Volume
SW-1-IP	23,800 cubic feet	100 mL
SW-2-IP	10,500 cubic feet	125 mL
SW-3-IP	12,500 cubic feet	100 mL
SW-4-IP	31,400 cubic feet*	75 mL
SW-5-IP	8,200 cubic feet	150 mL
SW-6-IP	6,800 cubic feet	200 mL
SW-7-IP	11,200 cubic feet	175 mL
SW-8-IP	4,100 cubic feet	200 mL
SW-9-IP	31,000 cubic feet	50 mL

* Except, time-weighted samples collected at this station during summer storm 2 and spring storm 2B

Immediately following each sampling event, the surface water samples collected at each station were processed for shipment to the analytical laboratory. The compositing vessel in each ISCO™ unit was removed and re-mixed, and aliquots were poured into the appropriate laboratory-supplied, pre-preserved sample bottles. Samples to be analyzed for dissolved metals were left unpreserved and shipped to the laboratory for filtering, preservation, and analysis.

All samples were analyzed for TSS. Samples from stations SW-4-IP and SW-9-IP were also analyzed for total (unfiltered) TAL metals, dissolved (unfiltered) arsenic, TCL SVOCs, and cyclohexanone (a non-TCL SVOC). In addition to TSS, the samples from the remaining stations were analyzed for selected metals (total arsenic, chromium, lead, and mercury; and dissolved arsenic) and selected SVOCs (bis(2-ethylhexyl)phthalate, diethylphthalate, PAHs, 4-methylphenol, and cyclohexanone). This analytical protocol was varied at three locations during the first and second spring storms due to the collection of an insufficient sample volume. The SW-6-IP sample for the first spring storm was not analyzed for SVOCs, and the SW-3-IP and SW-5-IP samples for the second spring storm were not analyzed for dissolved arsenic. Additionally, none of the samples from the second spring storm (2A) were analyzed for SVOCs due to a laboratory error; samples were collected from a third spring storm (spring storm 2B) and analyzed only for SVOCs to obtain this data. Table 2-3 presents a sampling summary for all base-flow and storm sampling events.

The work plan also called for geotechnical analysis of suspended sediments from each sampling station and calculation of settling velocities for suspended solids at the perennial stations. However, insufficient suspended sediment volume was present in the surface water samples to perform any of these analyses.

Temperature, dissolved oxygen, and turbidity were measured weekly at three locations in the HBHA Pond (north, central, south) during the summer, fall, and spring to document water quality conditions in the pond during surface water sampling periods and to determine when turn-over was occurring.

Stage-Discharge Monitoring – Automated stage-discharge monitoring was performed throughout the period of ISCO™ sampler deployment (July through November 2000, and mid-March through May 2001 for the ephemeral stations; July through mid-December 2000, and mid-March through May 2001 for SW-1-IP and SW-4-IP; July through mid-December 2000, and

mid-March through June 2001 for SW-9-IP). Flow stage and velocity measurements were taken and recorded by the automated samplers at each station at 2 minute intervals throughout the deployment period.

Manual discharge measurements were taken periodically to calibrate the accuracy of the ISCO™ flow sensor data. The manual measurements were taken during the retrieval of the samples collected for water quality monitoring, at each monitoring station exhibiting flow at that time. For open channels, the “partial section” method recommended by the USGS was used to calculate discharge. For culverted stations, flow was measured and discharge was calculated using standard geometric tables.

2.1.5.5 Final GSIP SOW Ecological Risk Investigation

The information presented in this section was summarized from the Toxicological Surface Water, Sediments Sampling and Fish Sampling Work Plan and Quality Assurance Project Plan for the Industri-plex Site, Woburn, Massachusetts, Menzie-Cura and Associates, Inc., July 7, 1999; the Final GSIP Ecological Risk Assessment Ecological Sampling Data Report, Menzie-Cura and Associates, Inc., February 2000; and the Fishery Survey, Industri-plex Site, Woburn, Massachusetts, U.S. Fish and Wildlife Service, April 2001. The Menzie-Cura and Associates (Menzie-Cura) documents were prepared on behalf of the ISRT. The U.S. Fish and Wildlife Service (USFWS) report was prepared on behalf of EPA. These documents are available in the Industri-plex Site information repository. Note: the sample location identifiers used for this investigation were changed for this RI report to distinguish them from similar location identifiers used in other investigations. The identifiers were changed by adding the prefix “MC” to the assigned station numbers (i.e. MC-01 through MC-13).

The ecological risk investigation field sampling program was conducted in June 1999 by Menzie-Cura and the USFWS, on behalf of the ISRT and EPA. The investigation included sampling and analysis of surface water, sediment, benthic invertebrates, vegetation, and fish, and conducting a fishery evaluation. The fishery evaluation and sampling were conducted jointly by Menzie-Cura and USFWS; the other parts of the investigation were conducted by Menzie-Cura. The objective of the investigation was to collect comprehensive data necessary to assess ecological and human health impacts from site-related contaminated sediments and surface water in the surface waters in vicinity of the Industri-plex Site. The investigation addressed the

tasks outlined in Sections 2.3.1 and 2.3.2 of the Final GSIP SOW issued by EPA on August 25, 1998. This section describes the ecological investigations.

Sample Locations

Thirteen sampling stations (MC-01 through MC-13) were selected for surface water and sediment sampling; benthic invertebrates were also collected at these stations. Eight of the thirteen stations were selected to characterize the Industri-plex Site and are located in the HBHA Ponds, stream segments within the HBHA wetlands, and the Aberjona River downstream of the HBHA. The remaining five stations are reference stations selected to represent background conditions. The reference stations are located in the Aberjona River immediately upstream of the Industri-plex Site, upper South Pond, Phillips Pond, and Halls Brook upstream of the site. Fish were collected from two site ponds (HBHA Pond and HBHA Wetland Pond 3) and two reference ponds (upper South Pond and Phillips Pond). Vegetation was collected from six locations, including two reference stations. Sampling stations are shown on Figure 2-6. A sampling summary for the ecological investigation is presented on Table 2-4.

Surface Water Sampling

Surface water samples were collected at the 13 sampling stations. At stations where the water depth was less than 3 feet, a single mid-depth sample was collected. At stations where the depth was greater than 3 feet (observed at three stations), two samples were collected: one from 1 foot below the water surface and one from 1 foot above the bottom. All samples were grab samples, collected using decontaminated sampling bottles (where water depth was less than 2 feet) or Kemmerer sample devices deployed from the side of a boat (in water deeper than 2 feet). The surface water samples were collected prior to sediment sampling at the same location.

All surface water samples were analyzed for dissolved metals, total metals, arsenic speciation, PCBs, pesticides, VOCs, SVOCs, TOC, TSS, and hardness. Water quality parameters, including dissolved oxygen, specific conductivity, temperature, and pH, were also measured at each station. At stations where the water depth was less than 3 feet, water quality measurements were taken at mid-depth. At deeper locations, measurements were made at the surface; above, within, and below the thermocline; and at the bottom. Table 2-4 presents a

sampling summary and the analytical method references. Sample locations are shown on Figures 2-6 and 2-5a.

Sediment Sampling

Two sets of sediment samples were collected at each of the 13 sampling stations: one set for chemical analysis to evaluate site-related chemicals in sediment, and one set for toxicity bioassays to evaluate whether chemicals in sediment are toxic to macroinvertebrates. The samples were collected concurrently, using the same sampling methods.

Sediment samples were collected from the 0- to 5-cm depth interval using a tall Ekman grab sampler. Multiple grabs were required to produce the volume of sediment required for all analyses and bioassays. Sediment from the first Ekman grab was placed directly into sample containers for VOC and AVS/SEM analyses. Sediment from the remaining grabs was transferred from the sampler into a stainless steel bowl and homogenized before being transferred into the sample containers for the remaining analyses and bioassays.

Chemical analyses of sediment samples from all sampling stations consisted of analysis for AVS/SEM, metals, PCBs, pesticides, SVOCs, VOCs, TOC, and grain size. Toxicity bioassays were conducted in two stages: Acute toxicity tests were conducted on samples from all stations with the amphipod *Hyallela azteca* and the insect larvae *Chironomus tentans*. Chronic toxicity tests for these two species were then conducted only on samples from stations where acute toxicity had not been demonstrated (i.e. those samples where the results of the acute toxicity tests did not significantly differ from those in reference station and control sediments). Table 2-4 presents a sampling summary and the analytical method references. Sample locations are shown on Figures 2-6 and 2-7a.

Benthic Macroinvertebrate Sampling

Benthic macroinvertebrates were sampled for two purposes: community evaluation and tissue analysis.

Sediments samples for benthic macroinvertebrate community analysis were collected from each of the 13 sample stations at the same time as collection of sediment for chemical and toxicity

analysis. Three samples were collected from each station and analyzed separately to provide a measurement of within-station variability. Samples were collected using a tall Eckman grab sampler. The contents of each grab was emptied into a bucket and then washed in a 0.5mm mesh sieve. The material remaining in the sieve was placed in a wide-mouth plastic jar and preserved with isopropyl alcohol. The samples were sorted in the laboratory, identified to the lowest practical taxonomic level, and counted. The data were analyzed for taxa richness, abundance, percent dominant taxa, and community composition.

Sediment sampling for benthic macroinvertebrate tissue analysis was attempted at all of the 13 sample stations. Because it can be a difficult to collect a sufficient volume of invertebrate biomass for tissue analysis, a framework was developed prior to sampling to provide guidance on when to discontinue sampling efforts at a particular location and to prioritize analyses of the samples collected. For details of the sampling and analysis framework, see the Menzie-Cura Work Plan/QAPP (July 1999) and Ecological Sampling Data Report (February 2000) referenced above. Sediment was collected with Ekman and petit Ponar grab samplers. The samples were processed on a washing table with an extra large sieve: sediment was washed through the sieve and benthic organisms were picked out with forceps, separated by taxa, and counted. Sample weights were estimated based on the size (length and width) of the invertebrates collected.

Macroinvertebrate samples for tissue analysis were obtained from all stations except MC-05 (in HBHA Pond), MC-10 (HBHA wetland stream), and MC-12 (Halls Brook reference location). Three different arthropods were collected for analysis: amphipods, chironomid larvae, and odonate nymphs. The three were analyzed separately if enough biomass was collected. At some stations amphipods and chironomid larvae were composited to produce enough biomass for analysis. Odonate nymphs were collected for analysis only at two reference stations (MC-02 and MC-03). The tissue samples were all analyzed for metals. If sufficient mass remained, analysis was also conducted for PAHs. Table 2-4 presents a sampling summary and the analytical method references. Sample locations are shown on Figure 2-6.

Vegetation Sampling

Aquatic plants were sampled to evaluate potential impacts to birds and mammals from feeding on vegetation growing in contaminated sediment and/or surface water. Two types of vegetation

were sampled for analysis of plant tissue: emergent vegetation was sampled to estimate potential impacts to aquatic mammals and submerged vegetation was sampled to estimate potential impacts to mammals and aquatic birds.

The emergent species, cattail (*Typha latifolia*) was collected from 5 of the 13 sampling stations. Samples were collected by carefully pulling or digging individual plants from the sediment, keeping the roots intact. The sediment was then washed from the roots, the root and bottom 1-foot of the stem were separated by hand or using a stainless steel blade, and the root and the lower stem were placed in separate zip-lock bags and preserved on ice. The samples were sent to a laboratory for metals analysis. Each sample sent to the laboratory for analysis was a composite of root or lower stem from five plants in the area of the sampling station.

Several submerged species were collected for analysis, including pondweed (*Potamogeton sp.*), coontail (*Ceratophyllum sp.*), water chestnut (*Trapa natans*), yellow water lily (*Nymphaea sp.*), and an unidentified grass-like plant (referred to as Plant C). Submerged species samples were collected from 5 of the 13 sampling stations. The sampling was conducted by carefully pulling or digging an individual plant from the sediment, keeping the roots intact. The sediment was then washed from the roots, the roots were separated from the upper plant (stems and leaves) by hand or using a stainless steel blade, and two sections were placed in separate zip-lock bags and preserved on ice. The samples were sent to a laboratory for metals analysis. Each sample sent to the laboratory for analysis was a composite of root or stem from five plants of the same species collected from the area of the sampling station.

Vegetation sampling locations, species, and analytical method references are presented on Table 2-4. Sampling stations are shown on Figure 2-6.

Fish Survey and Sampling

The USFWS (representing EPA) and Menzie-Cura (representing ISRT) jointly conducted a field investigation for the fishery survey for the Industri-plex Site in June 1999. The objectives of the survey were to evaluate the species diversity, abundance, and health of the fish populations in two ponds on site; evaluate physical habitat quality features to support different species; and determine body burdens of contaminants in fish tissue for use in the human health and ecological risk assessments (USFWS, 2001).

Fish sampling was conducted at two ponds on the site (HBHA Pond and HBHA Wetland Pond 3) and two reference ponds (upper South Pond and Phillips Pond) to obtain samples for tissue analysis and to assess the fish populations at the site and reference locations. Sampling was conducted primarily by boat electrofishing, and also using gill nets, trot lines, and eel pots.

All fish captured were inspected, weighed, and measured. A subset of the captured fish was selected for tissue analysis. The fish selected for analysis represented three different trophic levels:

- foraging species – pumpkinseed sunfish
- bottom feeding species – brown bullhead and white sucker
- predatory species – largemouth bass

The forage fish were analyzed whole. The other (larger) fish were filleted and dissected by Menzie-Cura personnel, and fillet, liver, and carcass (offal) samples were analyzed for each fish. All fish tissue samples (whole, fillet, liver, carcass) were analyzed for metals. In addition, arsenic speciation analysis was performed on fish fillet samples. Table 2-4 presents a sampling summary and the analytical method references. The ponds where fish sampling was conducted are shown on Figure 2-6.

2.1.6 Industri-plex Site Sub-Slab Soil Gas Investigation

The information presented below was summarized from the Sub-Slab Soil Gas Sampling Letter Report (Roux, July 19, 2004) and the Industri-plex Superfund Site Sub-Slab Sampling Guideline (EPA November 3, 2003) and associated correspondence between EPA and the ISRT (included in Appendix 2B-6). Refer to these documents for additional information on the investigation.

A soil gas investigation was conducted by Roux on behalf of the ISRT in May and June 2004 to aid in the assessment of potential human health risks posed by VOC vapor intrusion into occupied buildings at the Industri-plex Site. The investigation was conducted voluntarily by the ISRT at the request of EPA to support the baseline HHRA for the site. The soil gas data from the investigation will be used in the HHRA to estimate indoor air concentrations and calculate potential risks inside the buildings. The sampling was performed in accordance with the Industri-plex Superfund Site Sub-Slab Sampling Guideline (EPA, 2003), modified as agreed in email

correspondence between ISRT and EPA (Rinaldi, 2003 and LeMay, 2003). The work was conducted outside the GSIP process.

The soil gas sampling was conducted at seven buildings on and adjacent to the Industri-plex Site where there was the potential for indoor air to be impacted by migration of vapors from the shallow groundwater (see Figure 2-8). At six of the buildings, a soil gas sample was collected from immediately beneath the concrete building slab. At the seventh building (the Sacco Property located at 41 Atlantic Avenue), soil gas samples were collected from two locations immediately outside the building because sub-slab sampling was not permitted by the owner. These two samples were collected from approximately 4 feet below ground surface, as close as possible to the building's exterior walls (Roux, 2004). A duplicate sub-sample was collected at one property.

The sub-slab soil gas samples were collected using summa canisters. The sample apparatus was installed by drilling an approximately 1-inch diameter hole through the concrete slab, creating an approximately 3-inch annular space in subslab materials, inserting a vapor probe into the annular space and filling the top of the hole with modeling clay to establish a tight seal around the hole to prevent indoor air from being introduced into the sample. The soil gas grab samples were collected in evacuated 6-liter canisters, using an approximately 2-minute sampling duration. The exterior samples at the Sacco property were collected in a similar manner, except that the sample probes were installed approximately 4 feet below the ground surface.

The soil gas samples were submitted to a laboratory for analysis of VOCs using EPA method TO-15. A sample of the modeling clay used to seal the annular space around the soil gas probe was also submitted for analysis of VOCs by EPA method 8260B. See the letter report (in Appendix 2B-6) for additional sampling details.

2.2 Multiple Source Groundwater Response Plan (MSGRP)

As discussed in Section 1, the original purpose of the MSGRP was to investigate potential contamination impacts on area-wide groundwater and surface water in the Aberjona River watershed from sources in the Northern Study Area, and to determine whether additional remedies may be necessary to clean up the aquifer within the Industri-plex study area. The

MSGRP was initially intended to focus on the Industri-plex Site and the associated study area south to I-95, but was ultimately expanded to include the Aberjona River south of I-95 to and including the Mystic Lakes (the area previously addressed by the Wells G&H Aberjona River Study). Consequently, the expanded MSGRP includes investigations conducted by various parties for both the Industri-plex Site MSGRP and the Wells G&H Site Aberjona River Study.

The investigations that focused on the Industri-plex Site study area and the combined Industri-plex/Aberjona River study area were conducted principally by TtNUS on behalf of EPA. The EPA New England Regional Laboratory (EPA NERL) conducted some sediment and soil sampling to supplement the investigations performed by TtNUS. In addition, EPA sponsored two investigations to support the MSGRP: 1) a natural attenuation study by the EPA Office of Research and Development (EPA ORD) to investigate transport mechanisms for metals in groundwater and sediments at the Industri-plex Site; and 2) an arsenic bio-availability study by researchers at the University of Missouri, Columbia, and Syracuse Research Corporation, Denver Colorado, to assess bio-uptake of arsenic from site sediments.

The initial investigation of the Wells G&H Aberjona River Study Area was conducted for EPA by Foster Wheeler (FW, formerly Ebasco) in 1995. The study then transitioned to Metcalf and Eddy (M&E), who conducted a follow up field investigation and data evaluation in 1997 to support the baseline risk assessments for the Wells G&H Site Aberjona River Study (OU-3).

The following sections describe all the investigations conducted by and on behalf of EPA in support of this MSGRP RI. Section 2.2.1 presents the investigations conducted for the Wells G&H Aberjona River Study, Section 2.2.2 describes the investigations conducted by TtNUS for the MSGRP, Section 2.2.3 describes the investigations conducted by EPA in support of the MSGRP. The investigations are presented chronologically within each section.

2.2.1 Wells G&H Aberjona River Study – Foster Wheeler and Metcalf & Eddy

Field investigations for the Wells G&H Aberjona River Study were conducted by FW and M&E on behalf of EPA in 1995 and 1997, respectively. FW conducted a comprehensive field investigation in 1995 that included sampling and analysis of surface water, sediment, fish, and plants from various locations within the Aberjona River Study Area. M&E took over the Aberjona River Study in 1996 and conducted supplemental sediment sampling in 1997. This

section summarizes these Southern Study Area investigations. Details of sampling and analytical methods are presented in the Baseline Human Health and Ecological Risk Assessment, Aberjona River Study Area (M&E, 2004) which is available in the Wells G&H Site information repository.

For the purposes of the baseline ecological risk assessment, the Aberjona River Study Area (the Southern MSGRP RI study area) was divided into six reaches defined based on similarity of habitat, species and accessibility. For purposes of continuity, the same reaches were applied to the human health risk assessment for the Southern Study Area. These divisions and an additional Reach 0 (for the Northern Study Area) will be used as applicable throughout this MSGRP RI. The reaches are described in the table below and are shown on Figure 2-1. The descriptions of Reaches 1 through 6 are summarized from the baseline risk assessment (M&E, 2003). See that report for additional description of the habitat of each area.

ABERJONA RIVER REACH LOCATIONS AND DESCRIPTIONS

Reach	Location	General Description
0	Northern Study Area – Includes Industri-plex Site and study area, northern section of Aberjona River and HBHA ponds and wetlands	Various habitat types – The area includes river segments in subsurface culverts, natural and engineered open channels; open water; and wetlands. Land use includes commercial, light industry, undeveloped, and residential property.
1	From I-95, south to Salem Street, including the Wells G&H wetlands	The river is generally shallow, slow-moving, and turbid as it passes through wetlands throughout most of reach. Land use includes commercial, light industry undeveloped, and residential property.
2	Salem Street south to the river crossing at Washington Street in Winchester, including the Cranberry Bog Conservation Area	The river is generally shallow, but relatively faster-flowing with benthic substrates consisting of embedded gravel and cobbles. Land use includes commercial, light industry, undeveloped, and residential property.
3	Washington Street South to Swanton Street, including Davidson Park	The river is similar to Reach 2, but includes a 1-acre pond at Davidson Park. Land use includes commercial, light industry, undeveloped, and residential property.

Reach	Location	General Description
4	Swanton Street south to Mill Pond	The river is culverted underground for approximately 0.3 miles near the start of the reach and includes two ponds (Judkins Pond and Mill Pond) in Winchester center. Land use includes commercial, light industry, undeveloped, and residential property.
5	Mill Pond outlet south to Upper Mystic Lake inlet	The river is similar to Reaches 2 and 3. Land use includes commercial, undeveloped, and residential property, but park land is the dominant use.
6	Upper Mystic Lake, including upper and lower forebays, and Lower Mystic Lake	This reach consists entirely of open water bodies: the forebays of Upper Mystic Lake and the Upper and Lower Mystic Lakes. Land use includes undeveloped, and residential property, but park land is the dominant use.

2.2.1.1 FW 1995 Field Investigation

FW conducted a comprehensive field investigation in July through September 1995 that included sampling and analysis of surface water, sediment, and biota from various locations within the Aberjona River Study Area. This section describes the sample locations, methods, and analyses used in the investigation. This information was summarized from Section 2 of the Aberjona River Study Area Baseline Risk Assessment (M&E, 2004). Additional information regarding the field investigation are presented in Appendix A.1 of that document and in the *Preliminary Data Compendium, Well G&H RI/FS, Operable Unit III, Aberjona River Study, sampling period July 31, 1995 to September 12, 1995* (FW, 1996), available in the Industri-plex Site information repository.

FW 1995 Investigation Sample Locations

Twenty one study area stations and five reference stations were established to collect sediment, surface water, and biota samples during the 1995 field investigation. The stations were selected to represent the three distinct types of aquatic habitat within the Aberjona River Study Area: river channel, surface water impoundments, and wetlands.

The 21 study area sample locations (stations 01 through 16 and 18 through 22) were selected to represent significant habitats for ecological receptors and areas where potential recreational use may allow for significant human exposure to contaminants in the surface water, sediment, or fish fillet tissue (M&E, 2004). Ten stations were located in the main channel of the Aberjona River; four stations were situated in Upper Mystic Lake; and seven stations were located in wetlands adjacent to the Aberjona River (M&E, 2004). Study area sample locations are shown on Figures 2-5b – 2-5d (surface water) and 2-7b – 2-7h (sediment).

Three local and two regional reference stations were located in areas representative of study area habitats, but not likely to be impacted by site- or other-contaminant sources. These were located in areas outside the main basin of the Aberjona River or upgradient of the influence of the Wells G&H and Industri-plex Sites, in areas unlikely to be significantly impacted by other sources of contamination. The three local reference stations (23, 24, and 25) were situated at the confluence of Lubbers Brook and the main channel of the Aberjona River; in the riverine wetlands of Maple Meadow Brook, a small tributary of the Aberjona River located upstream of the Wells G&H and Industri-plex Superfund Sites; and at Horn Pond, an impoundment of Fowl Brook, a tributary of the lower Aberjona River. Two regional stations (26 and 27) were located at Wrights Pond, to the east of the study area; and in the Shawsheen River, to the northwest of the study area (M&E, 2004). Reference sample locations are shown on Figures 2-5e, 2-5f (surface water), 2-7i and 2-7j (sediment).

FW 1995 Sediment Investigation

Sediment samples were collected at all 21 study area stations and five reference stations. Multiple sediment samples were collected at each sample station because historical data identified sediment as containing the largest number of contaminants and because of its tendency to act as a sink for both organic and inorganic contaminants in aquatic environments (M&E, 2004). Sediment and surface water sampling progressed from downstream to upstream stations. At each sample station, the surface water sample was collected prior to collecting the sediment samples.

At most sampling stations three sediment samples were collected for comprehensive chemical analyses to allow for evaluation of localized contaminant distribution. At each station with three samples, a sample was collected at a central location and two additional samples were

collected within 50 feet of the central point. The central location was designated with an “01” (eg. SD-08-01-FW for sediment station 08, sample 01, collected by Foster Wheeler); the other samples were designated “02” and “03” (eg. SD-08-02-FW and SD-08-03-FW). The location of the central (“01”) sample at each station was recorded with a GPS unit; the relative locations of the other samples were described in field notes and are designated as approximate on the figures in this section. (M&E, 2004)

Expanded sampling was conducted at three stations that were identified as significant for the baseline human health risk assessment: station 01 (Upper Mystic Lake Sandy Beach), station 07 (Aberjona River at Davidson Park), and station 09 (Cranberry Bog Conservation Area on the Aberjona River). Ten samples were collected for chemical analyses at each of these stations. The location of the (-01) sample at each station was recorded with a GPS unit; the locations of the other samples were approximated as described above and noted on the figures in this section.

Additional samples were collected at six study area stations and two reference stations for bioassay testing with benthic invertebrates (10-day toxicity tests). The purpose of the toxicity testing was to determine whether survival or growth of organisms exposed to study area sediment would be significantly different than the survival or growth of organisms exposed to reference or control sediment.

Sediment samples were collected as near to the surface water sampling location as possible, where undisturbed sediment existed. The samples were collected from a depth of 0 to 6 inches using a stainless steel sampling device. Sediments collected for VOCs analysis were placed directly into the sample bottle. Sediment for the remaining analyses was placed into a stainless steel bowl and thoroughly mixed before being transferred into the appropriate sample bottles.

Sediment samples from all stations were analyzed for VOCs, SVOCs, pesticides/PCBs, metals, total organic carbon (TOC), grain size, and acid volatile sulfides/simultaneously extracted metals (AVS/SEM). In addition, 10-day toxicity tests were conducted on samples from six study area stations and two reference stations, as described above. Table 2-5 presents the sampling summary and analytical method references for all sediment sample stations. Sediment sample locations are shown on Figures 2-7b through 2-7j.

FW 1995 Surface Water Investigation

Surface water samples were collected at 17 of the 21 study area stations and five reference stations where sediment samples were collected. Four wetland stations (Stations 19 through 22) were not sampled because standing water was not present during the 1995 field investigation. Surface water sampling stations are shown on Figures 2-5b through 2-5f.

Surface water samples were collected by approaching the sample station from downstream and filling the sampling container directly from the body of water. In cases where the water was too shallow to dip the sampling container, a small transfer container was used. A transfer container was also used to collect samples for VOCs analysis because the sample containers for that analysis were pre-preserved. For other sample analyses requiring preservation, the preservatives were added to sample containers after sample collection.

Surface water samples were analyzed for VOCs, SVOCs, pesticides/PCBs, total metals, and a suite of water quality parameters including total dissolved solids (TDS), total suspended solids (TSS), and dissolved organic carbon. Table 2-6 presents the analytical method references and sample summary for all sample stations.

FW 1995 Fish Investigation

Fish and crayfish sampling were conducted jointly by FW and the USFWS between July and September 1995. Fish and crayfish samples were collected throughout the Aberjona River Study Area and from reference stations to support the baseline human health and ecological risk assessments for the Aberjona River Study Area.

Over 80 fish samples were collected in the Aberjona River Study Area and 32 fish samples were collected from reference stations at Horn Pond and Wright Pond. Four categories of fish samples were collected and analyzed: small fish, large fish, fillet, and offal. Small fish were collected primarily to support evaluation of the heron in the baseline ecological risk assessment. Contaminant concentrations in large fish, fish fillet, and offal were used to evaluate the health of fish communities in the study area. Fish fillet samples were also analyzed to support the baseline human health risk assessment (M&E, 2004).

Eight crayfish samples, each consisting of several individuals per sample, were collected in the Aberjona River Study Area. The crayfish samples were collected from Reaches 1, 2, 3, and 5. Two reference samples were collected from the Shawsheen River.

Table 2-7 presents a fish sampling summary. Sampling details for individual fish, including species, length, weight, and other observations can be found in Appendix A.1 of the Aberjona River Study Area Baseline Risk Assessment report (M&E, 2004).

The primary method of fish collection was electro-shocking; however, seines and trot lines were also used. Crayfish were collected by seining. The fish and crayfish samples were analyzed for SVOCs, pesticides/PCBs, metals, percent lipid, and percent moisture.

FW 1995 Plant Tissue Investigation

Wetlands vegetation sampling was conducted during late August and early September 1995. Herbaceous plant samples were collected from three stations (18, 20, and 21) within the 38-acre Wells G&H wetland. Two composite plant tissue samples were obtained from the 01 and 02 sediment sampling locations. One composite sample was also collected from reference station 23 for a total of six samples. See sediment sample location Figures 2-7b and 2-7j for locations of plant sampling.

Samples from station 18 were collected adjacent to a ponded area characterized by cattails and common reed, with an under story of arrowhead, bulrush and spike rush. Other species present included purple loosestrife and touch-me-not. The composite tissue samples consisted of cattail, common reed, arrowhead, bulrush and spike rush.

Samples from Station 20 were collected from a wetland area adjacent to a nearly stagnant pool. Dominant species at this location were cattails, purple loosestrife and touch-me-not. The composite tissue samples consisted of cattail, burreed, arrowhead, and spike rush.

Samples from Station 21 were collected from a floating bog in the northwest portion of the Wells G&H wetland. Dominant species at this location were cattails, spike rush, arrowhead, grasses, sedges and rush. The composite tissue samples consisted of cattail, common reed, arrowhead, and spike rush.

Samples from reference Station 23 were collected from the area adjacent to Lubbers Brook at Concord Street. The composite tissue samples consisted of cattail, pondweed, pickerelweed and burreed.

Plant samples were collected by hand. Samples included roots, stems, and leaves. Only the basal portions of stems and leaves on tall emergents such as cattails and reeds were included. The methods of collection and compositing the plant samples are described in the *Final Field Operations Plan* (Ebasco, 1995).

The plant tissue samples were analyzed for SVOCs, pesticides/PCBs, metals, and percent moisture. Table 2-8 presents the plant sampling summary.

2.2.1.2 Metcalf and Eddy 1997 Field Investigation

M&E conducted additional sampling in November 1997 to clarify some uncertainty associated with the 1995 sediment sampling results. This sampling round consisted of only sediment sampling and analysis. This section describes the sample locations, methods, and analyses used in the 1997 sampling round. This information was summarized from Section 2 of the Aberjona River Study Area Baseline Risk Assessment (M&E, 2003). See that document, available in the Industri-plex Site information repository, for additional details about the field investigation.

M&E 1997 Sediment Sample Locations

The 1997 field investigation involved collecting additional sediment samples from most of the stations sampled during the 1995 investigation. A total of 28 sediment samples were collected for comprehensive analysis from 17 of the 21 original study area sample stations and two of the five original reference stations. One to three samples were collected at each station, as indicated on Table 2-5.

In addition, as in the 1995 investigation, sediment samples were collected at six study area stations and two reference stations for bioassay testing with benthic invertebrates (10-day toxicity tests).

The 1997 sample stations were located as close to the corresponding 1995 sample stations as possible. All sample stations were located by GPS. A sediment sampling summary is presented on Table 2-5. Sediment sampling locations are shown on Figures 2-7b through 2-7i.

M&E 1997 Sediment Sampling Methods and Analyses

Sediment samples were collected from a depth of 0 to 6 inches. At most locations, sampling was conducted from a boat, using an Eckman dredge with a 6-foot handle. At shallow locations, sediment was collected with tubular modified syringes and coring devices such as bulb planters. (M&E, 2003)

Sediments for VOCs and AVS/SEM analyses were placed directly into the appropriate sample containers. Sediment for the remaining analyses was placed into a stainless steel colander lined with large pieces of filter paper to promote dewatering. Additional filter paper was placed on top of the sediment to aid in the dewatering. The dewatered sediment was then thoroughly mixed before being transferred into the appropriate sample bottles for the remaining analyses.

Sediment samples collected for comprehensive analysis were analyzed for VOCs, polynuclear aromatic hydrocarbons (PAHs), pesticides/PCBs, low concentration metals, AVS/SEM, total combustible organics (TCO), grain size, pH, and percent moisture. In addition, 10-day toxicity tests were conducted on samples from six study area stations and two reference stations, as described above. Table 2-5 presents the analytical method references and sample summary for all sample stations.

2.2.2 MSGRP Northern and Southern Study Areas – TtNUS

TtNUS conducted several phases of MSGRP field investigations at the Industri-plex Site and Aberjona River study areas from July 2000 through January 2003 on behalf of EPA. The investigations included sampling and analysis of groundwater in the Northern Study Area (i.e. north of I-95), surface water and sediment throughout the MSGRP RI study area, and soil on properties adjacent to the Industri-plex Site and in the Aberjona River floodplain. The investigations are summarized below. Additional details of sampling and analytical methods are provided in the *Quality Assurance Project Plan - Revision 1.0, Industri-plex Site – MSGRP*

(TtNUS, April 2002). All sample log sheets from the MSGRP investigations are included in Appendix 2A, arranged by media.

2.2.2.1 Sediment Investigations

TtNUS conducted several phases of sediment sampling between July 2000 and October 2002 to collect data to evaluate the nature and extent of sediment contamination in the MSGRP RI study area and to support the baseline human health and ecological risk assessments for the study area.

Sediments were collected from river, lake, and wetland environments, in areas sometimes or always submerged underwater. In general, all sediment samples were collected to assist in understanding the nature and extent of contamination. A subset of samples was targeted specifically to locations accessible to humans and animals and with water shallower than 2 feet deep, to support the evaluation of potential human and ecological risks.

Sample collection methods were consistent throughout the investigations. All sediment samples were collected from a sediment depth interval of 0 to 6 inches. Sediment samples were collected using either a hand tool such as a stainless-steel scoop or auger, or an Eckman grab sampler. In general, hand tools were used at locations where little or no standing water was present and Eckman samplers were used at submerged locations. The Eckman samplers were deployed on a rope line over the side of a small boat in deep water and attached to a pole and used while wading at shallower locations. Sediment samples were collected from downstream to upstream locations.

Sediment to be analyzed for VOCs was placed directly into the appropriate sample container(s). Sediment for all other analyses was placed into a stainless steel bowl and thoroughly mixed to homogenize the sample; and excess water was carefully decanted to avoid discarding sediment fines. The homogenized sediment was then transferred to the appropriate sample containers.

Details of the individual investigations are described below.

July 2000 Sediment Investigation

Sediments were collected from several locations in the Southern Study Area in July 2000 to fill data gaps from previous investigations. The samples were collected from a sediment depth interval of 0 to 6 inches using the standard methods described in Section 2.2.2.1. Sample locations, objectives, and analyses conducted are described below.

Wells G&H Wetlands/Floodplain – The previous Wells G&H sediment sampling within the Wells G&H wetland focused on the collection of sediments for evaluation of nature and extent of contamination and ecological risk assessment. Sediment sampling locations for this investigation were targeted to allow evaluation of potential human health risk exposures. Samples were collected from along the water's edge of the Aberjona River wetland/floodplain at 40 locations in three main areas:

- Well H (station WH, locations 01-10) – 10 locations along the east side of the Wells G&H wetland/floodplain near Well H
- Well G/Salem Street East (station WG, locations 01-20) – 20 locations along the east side of the Wells G&H wetland/floodplain near Well G
- Salem Street West (station WS, locations 01-10) – 10 locations along the west side of the wetland/floodplain at a residential property located immediately west of the Salem Street bridge

Samples were analyzed for total metals and cyanide. In addition, 20 percent of the samples were randomly selected and also analyzed for hexavalent chromium and sulfides. Sample stations and analyses performed are identified on Table 2-5; sample locations are shown on Figure 2-5b.

Aberjona River – Previous sampling of the river did not include the wider areas of the river just upstream of Montvale Avenue and adjacent to the condominium complex located at 171 Swanton Street in Winchester, Massachusetts. These depositional areas were sampled in the July 2000 investigation to achieve a better understanding of the nature and extent of metals contamination and supplement the ecological risk assessment. Sediment samples were collected from the following locations:

- Aberjona River Upstream of Montvale Avenue (AM-01) – One sample location in a depositional area of the Aberjona River upstream of Montvale Avenue
- Aberjona River at the 171 Swanton Street condominium complex (AS-01 and -02) – Two sample locations in a depositional area of the Aberjona River near the condominium complex

Samples were analyzed for total metals and cyanide, hexavalent chromium, and sulfides. Sample locations and analyses performed are identified on Table 2-5; sample locations are shown on Figures 2-7d and 2-7e.

Aberjona River Outlet (station AO, locations 01-05) – Previous sampling identified elevated metals concentrations in sediment at one sample location (SD-04-02) in the Upper forebay of the Upper Mystic Lake, just south of the Aberjona River outlet. Five additional samples were collected during the July 2000 investigation, in the general area of the previous sample, to confirm the presence of elevated metals, better characterize the nature and extent of metal contamination in the area, and support the ecological risk assessment.

The samples were analyzed for total metals and cyanide. One sample was also analyzed for hexavalent chromium and sulfides. Sample locations and analyses performed are identified on Table 2-5; sample locations are shown on Figure 2-7g.

Mystic Lakes – Previous sampling did not include sediment samples from the center of the Upper or Lower Mystic Lakes or the Upper Mystic Lake forebays. Under this investigation, sediment samples were collected from the center of each lake and forebay to better define the nature and extent of metals contamination within the depositional areas of the lakes. Sediment samples were collected from a total of 11 locations in the Mystic Lakes and forebays, distributed as follows:

- Upper forebay – three locations (station UF, locations 01-03)
- Lower forebay – two locations (station LF, locations 01-02)
- Upper Mystic Lake – three locations (station UM, locations 01-03)
- Lower Mystic Lake – three locations (station LM, locations 01-03)

All samples were analyzed for total metals and cyanide. One sample from each body of water was also analyzed for hexavalent chromium and sulfides. Sample locations and analyses performed are identified on Table 2-5; sample locations are shown on Figure 2-7g.

Mill Pond and Judkins Pond – Sediment samples were collected from depositional areas within Mill Pond and Judkins Pond in the July 2000 investigation to assist in determining the nature and extent of metals contaminants from the Aberjona River within each of the ponds and to supplement the human health and ecological risk assessments. The following samples were collected:

- Mill Pond – two locations (MP-01 and -02);
- Judkins Pond – one location (JP-01)

All samples were analyzed for total metals, cyanide, hexavalent chromium, and sulfides. The sample locations and analyses performed are identified on Table 2-5; sample locations are shown on Figure 2-7f.

November 2000 Sediment Investigation – Wildwood Property

In November 2000 TtNUS collected sediment samples in the Wells G&H wetlands west of the Aberjona River, adjacent to the Wildwood Property. This area had not been sampled previously. Samples were collected to better evaluate the nature and extent of metals contamination and to support the human health risk assessment.

Composite sediment samples were collected at 12 locations along the wetland perimeter adjacent to the Wildwood Property (WW-01 through -12). Each sample was collected from a sediment depth interval of 0 to 6 inches using the standard methods described in Section 2.2.2.1.

All samples were analyzed for total metals. The Wildwood property sample locations and analyses performed are identified on Table 2-5; sample locations are shown on Figure 2-7b.

February 2001 Sediment Investigation

Sediments were collected from several locations in the Southern Study Area, and one located in the Northern Study Area, in February 2001 to fill data gaps from previous investigations. The samples were collected from a sediment depth interval of 0 to 6 inches using the standard methods described in Section 2.2.2.1. Sample locations, objectives, and analyses conducted are described below.

Wells G&H Wetlands – Additional sediment samples were collected within the Wells G&H wetlands during this investigation to verify previous data and fill data gaps from previous investigations. The samples were collected to achieve a better understanding of the nature and extent of contaminants, and to better assess ecological risk. The locations selected for this investigation differ from the locations sampled from the Wells G&H Wetlands in July 2000 to support the human health risk assessment. A total of 13 composite sediment samples were collected from four stations, as indicated below:

- TT22 (locations 01-03) – three locations in the northeast portion of the Wells G&H wetlands near the rifle range
- TT27(locations 01-04) – four locations on the west side of the Wells G&H wetlands
- TT28 (locations 01-03) – three locations on the east side of the Wells G&H wetlands, north of Well H
- TT29 (locations 01-03) – three locations on the east side of the Wells G&H wetlands between Wells G and H

All samples were analyzed for total metals. Samples from three locations were also analyzed for hexavalent chromium and sulfides. The Wells G&H wetland sample locations and analyses performed are identified on Table 2-5; sample locations are shown on Figure 2-7b.

Cranberry Bog Conservation Area – Sediment samples were collected from this area to assist in the assessment of human health and ecological risk. Sediment samples to assess human health risk (CB series) were collected from areas where public access is evident and from locations that abut residential properties. Sediment samples collected to assess ecological risk (TT series) were collected within or adjacent to wetland channels in clusters of three. Sediment samples were collected from the following stations:

- CB-01 (locations 01-10) – 10 locations approximately 60 feet apart along the outer edge of the bog in northeast portion of the Cranberry Bog Area
- CB-02 (locations 01-10) – 10 locations approximately 50 feet apart along the outer edge of the bog in southeast portion of the Cranberry Bog Area
- CB-03 (locations 01-12) – 12 locations approximately 60 feet apart in the west-central portion of the Cranberry Bog Area
- TT-30 (locations 01-03) – three locations along wetland channels north of the Cranberry Bog Area
- TT-31 (locations 01-03) – three locations along wetland channels north of the Cranberry Bog Area
- TT-32 (locations 01-03) – three locations along edge of the Aberjona River north of the Cranberry Bog Area
- TT-33 (locations 01-03) – three locations along edge of the Aberjona River south of the Cranberry Bog Area

A total of 44 composite sediment samples were collected from depositional areas described above. All samples were analyzed for total metals. Twenty percent of the samples were also analyzed for hexavalent chromium and sulfides. The Cranberry Bog Conservation Area sample locations and analyses performed are identified on Table 2-5; sample locations are shown on Figure 2-7c.

East Drainage Ditch – Most of the East Drainage Ditch is located within the area addressed by the Industri-plex soil remedy. Approximately 3,000 mg/kg chromium was found in drainage ditch sediments at a facility (Olin Chemical Company) located immediately upstream of the Industri-plex Site. Samples were collected from the East Drainage Ditch and New Boston Street Drainway to identify the nature and extent of contaminants and to evaluate possible impacts to the Industri-plex soil remedy from the off-site source.

A total of 10 composite sediment samples (ED-01 through ED-10) were collected from depositional areas in the East Drainage Ditch. All samples were analyzed for total metals. Twenty percent of the samples were also analyzed for hexavalent chromium and sulfides. The East Drainage Ditch sample locations and analyses performed are identified on Table 2-5; sample locations are shown on Figure 2-7a.

Wildwood Property – One sample was collected in the Wells G&H wetlands adjacent to the Wildwood Property during this investigation to confirm the results of the November 2000 sampling. The sample was collected at station WW-08 as near to the original location as possible. The sample was analyzed for total metals, hexavalent chromium, and sulfides. The sample location and analyses performed are identified on Table 2-5; sample locations are shown on Figure 2-7b.

June 13, 2001 Sediment Investigation – Chromium Evaluation

Sediments were collected from three locations on June 13, 2001 to evaluate the presence of hexavalent chromium concentrations found in previous sampling. One composite sample was collected at each of three locations (ED-03, WW-08, CB-02-09) where disparities had been identified between the total chromium and hexavalent chromium results.

The samples were collected as near to the previous sampling locations as possible. The samples were collected from a sediment depth interval of 0 to 6 inches using the standard methods described in Section 2.2.2.1.

Sediment samples were analyzed for total metals, hexavalent chromium, and sulfides. Hexavalent chromium analysis was by the same method (colorimetric analysis) used in the previous sampling rounds. The sample locations and analyses performed are identified on Table 2-5; sample locations are shown on Figures 2-7a, 2-7b, and 2-7c.

June 18 through 27, 2001 Sediment Investigation – Triad Sampling

Triad/sediment sampling was conducted during this investigation to better evaluate ecological risk in different environments (wetland, stream, and pond) throughout the MSGRP RI study area. The triad sampling approach includes both chemical and biological analysis of the sediment to provide a better understanding of the contamination in the sediment, the type of macroinvertebrate population in the sediment, and the toxicity impacts of the sediment contamination on the biological population.

Twenty composite sediment samples were collected for the triad/sediment sampling. The samples were collected from previous sample locations in depositional areas of the Wells G&H

Wetlands, the wetlands adjacent to the Wildwood Property, Cranberry Bog Conservation Area, Judkins Pond, upper forebay of the Mystic Lakes; and reference locations Phillips Pond, South Branch of the Aberjona River, and Halls Brook. Triad/sediment sample locations and analyses performed are identified (as investigation TtNUS – 6/2001 (t)) on Table 2-5; locations sampled during the triad investigation are shown on Figures 2-7a through 2-7h (except 2-7e).

All sediment samples were collected from a sediment depth interval of 0 to 6 inches using the standard methods described in Section 2.2.2.1.

The samples were analyzed for VOCs, SVOCs, pesticides/PCBs, total metals, AVS/SEM, TOC, and grain size. Benthic invertebrate toxicity testing and benthic community assessment were also performed on the samples. The toxicity testing included short term (10 day) and long term (42-day/lifecycle) survival and growth tests for two types of benthic organisms: amphipod (*Hyallela azteca*) and midge (*Chironomus tentans*). The benthic community assessment included identifying the types of benthic species and counting the total number of benthic organisms within the sediment.

November 2001 Sediment Investigation

Sediment samples were collected from along the shoreline of the Halls Brook Holding Area (HBHA) in November 2001 to assist in evaluation of human health risk. This area had not been sampled for this purpose in previous investigations. The sample locations were divided into three HBHA stations:

- HB01 (locations 01-10) – 10 locations in the northern portion of the HBHA, along the HBHA Pond
- HB02 (locations 01-10) – 10 locations in the mid portion of the HBHA, along the shoreline of the HBHA wetland
- HB03 (locations 01-10) – 10 locations in the southern portion of the HBHA, along the shoreline of the HBHA wetland

All sediment samples were collected from depositional areas, from a sediment depth interval of 0 to 6 inches using the standard methods described in Section 2.2.2.1.

All samples were analyzed for total metals. Six samples were also analyzed for hexavalent chromium and sulfides. Hexavalent chromium analysis was performed using two methods (colorimetric method and ion chromatography) in order to evaluate which method was better suited for analysis of the wetland sediments. This evaluation was conducted because some previous results from colorimetric analysis showed hexavalent chromium concentrations higher than the total chromium concentrations and because the laboratory reported matrix interferences and technical difficulties with the colorimetric analysis.

The HBHA sample locations and analytical methods performed are identified on Table 2-5; sample locations are shown on Figure 2-7a.

October 2002 Sediment Investigation

In this investigation, sediment samples were collected from six previously sampled locations at five stations (WG-10, WH-02, WS-08, WW-06, CB03-06, and CB03-10) in the Southern Study Area where to further evaluate the presence of hexavalent chromium in study area wetlands and to support risk assessment decisions regarding calculation of risks from chromium. The six locations sampled were those with the highest total chromium results in previous investigations.

The samples were collected as near to the previous sampling locations as possible. All samples were collected from a sediment depth interval of 0 to 6 inches using the standard methods described in Section 2.2.2.1.

All samples were analyzed for total metals, hexavalent chromium, and sulfides. Hexavalent chromium analysis was performed using the ion chromatography method. Ion chromatography was used because, based on a comparison of the two methods in the November 2001 investigation, it was considered superior to the colorimetric method used in previous sampling due to matrix interferences. The locations sampled and analyses performed for the October 2002 investigation are identified on Table 2-5; the sample locations are shown on Figures 2-7b and 2-7c.

2.2.2.2 Surface Water Investigation

TtNUS conducted a comprehensive surface water investigation within the Aberjona River watershed to assess the nature and extent of metals contamination, evaluate contaminant migration from the Industri-plex Site into and throughout the river, and to support the evaluation of human health and ecological risks.

TtNUS constructed, operated, and maintained 10 automated surface water sampling/monitoring stations along the HBHA, Aberjona River, and the Mystic Lakes and one automated flow monitoring station along a small tributary stream to the Lower Mystic Lake. TtNUS collected surface water data at the eleven stations over approximately 18 months from May 2001 through October 2002, capturing base flow, storm flow, and seasonal conditions. The surface water investigation is described below.

Monitoring Station Locations and Equipment

Prior to beginning the investigation, several possible monitoring station locations were evaluated. Consideration was given to the confluence of tributaries, location of watershed sub-basin boundaries, locations of previous and existing monitoring/gauging stations (i.e. Industri-plex Site Remedial Trust and United States Geological Survey stations), site access, and stream channel configuration. The following locations were selected with the assistance of EPA and USGS:

- Station 1 – Halls Brook, upstream of its discharge into HBHA Pond
- Station 2 – HBHA Pond outlet
- Station 3 – Aberjona River at Mishawum Road, prior to the confluence with Halls Brook Holding Area
- Station 4 – Halls Brook Holding Area, discharge control structure at Mishawum Road prior to the confluence with Aberjona River
- Station 5 – Salem Street bridge (Woburn), south of the Wells G&H wetlands
- Station 6 – Aberjona River downstream of the Montvale Avenue bridge (Woburn)
- Station 7 – Aberjona River at the Swanton Street bridge (Winchester)
- Station 8 – Aberjona River at the USGS gauging station, off of Mystic Valley Parkway (Winchester)

- Station 9 – Upper Mystic Lake dam, near the Medford Boat Club (Arlington)
- Station 10 – Lower Mystic Lake outlet, at High Street (Rt. 60) bridge (Medford)
- Station 11 – Mill Brook outlet into the Lower Mystic Lakes (Arlington)

Surface water samples and flow measurements were taken at stations 1 through 10. Station 11 was used strictly for flow monitoring, to evaluate the contribution of flow from Mill Brook into the Lower Mystic Lakes. Station locations are shown on Figure 2-5g and Figures 2-5a through 2-5d.

Stations 1 through 10 were equipped with automated samplers; continuous data-logging instruments to measure water quality parameters, stage, and flow (except at Station 9); and an automated rain gauge. At Station 9, flow and stage conditions were not monitored due to the lack of an intact control structure. Station 11 was equipped only with an area velocity flow meter. Each station was solar powered and equipped with a cellular telephone for data retrieval and remote control of the auto-samplers.

Each sampling station was equipped with two ISCOTM Model 6712 automated samplers (a primary unit and a secondary unit to serve as a backup unit in case of primary unit failure) and a tipping bucket rain gauge to monitor conditions and collect samples during storm events. Each sampler was equipped with 24 1-liter plastic sample bottles to collect samples for metals analysis. In addition, coupled with a YSI Model 6820 multi-probe sonde, the auto-samplers measured velocity, stage, pH, conductivity, specific conductance, ORP, DO, temperature, turbidity, and rainfall. These parameters were measured at 5-minute intervals and recorded at 15-minute intervals, 24-hours per day. See Appendix 2C, *Draft Evaluation of Flow, Suspended Sediment and Heavy Metals in the Aberjona River, Industri-plex Site, Woburn, MA* (TtNUS, 2005) for details of the equipment installed at each monitoring station.

Surface Water Sampling Method Evaluation: May 2001

In May 2001, TtNUS conducted a limited surface water sampling program to evaluate a proposed sample collection method for the automated samplers. The evaluation was necessary because most methods used to collect representative surface water samples are designed for collection of grab-samples and are dependent on the depth of water at the sampling location. In general, the depth of the sampler or sample intake is determined based on the depth of the

river. These methods are not practical for use with automated samplers because the automated samplers would be unattended during storm events, thus the sample intake could not be adjusted to conform to the fluctuating depth of the river.

During a previous surface water investigation by the ISRT, their consultant, Roux Associates, devised an alternative sampling device for the automated samplers. The sampler consisted of a slotted PVC pipe with a sampling port incorporated into the side of the pipe close to its base. The pipe was positioned at a fixed location close to the center of the river channel and the sample was drawn from the sampling port through polyethylene tubing. The premise of the sampler was that water from the entire water column would enter the PVC pipe from the various slots and would mix to create a representative sample of the entire water column. Given that the river water-depths were generally less than 3 feet; this approach seemed technically acceptable.

To evaluate this alternative sampling method, TtNUS collected surface water samples using this method and two standard grab sampling methods simultaneously and compared the analytical results. The two standard sampling techniques used were: 1) collection of a “direct-dip” grab sample from a depth equal to 0.6 of the total water column; and 2) use of a depth-integrated sampler to collect an integrated sample from throughout the water column.

On May 21, 2001, 18 samples were collected at Stations 2 and 10 using the three sampling methods. Samples were shipped to and analyzed by the EPA New England Regional Laboratory (NERL) for total suspended solids (TSS). The sample results indicated that there was very little variability between the sampling methods. As a result, the slotted PVC pipe sampler was considered acceptable for use with the automated samplers and was installed at each sample station at a fixed point as close to the center of the river channel as possible. Refer to Appendix 2C for specific details and the analytical comparison.

Baseflow Sampling: July 2001 – October 2002

To evaluate surface water chemistry and flow during base-flow conditions, monthly grab samples were collected at each of the 10 sampling stations and flow measurements were taken at all 11 stations from July 2001 through October 2002. One additional station (SW-ARB – Aberjona River upstream of Station 3) was added beginning in June 2002 to investigate the

potential source of contaminants observed at Station 3. The baseflow surface water samples were analyzed for total metals, dissolved metals, and TSS at off-site laboratories. In addition, temperature, pH, dissolved oxygen, specific conductance, and turbidity were measured in the field. A sampling summary is presented on Table 2-6. Sampling stations are shown on Figures 2-5a through 2-5d and 2-5g .

The base-flow samples were collected using the “direct-dip” method: submerging a sample bottle or transfer container to the required depth (0.6 of the total water column) and retrieving a sample. Unpreserved sample bottles were filled directly or using a clean transfer jar. Pre-preserved sample bottles were filled using a clean transfer jar.

Samples to be analyzed for dissolved metals were filtered immediately after collection (and prior to preservation) using a peristaltic pump, disposable silicone and polyethylene tubing, and disposable in-line filters. Most samples were filtered with only a 0.45-micron filter. Samples with turbidity of 20 NTU or greater were filtered with both 1.0-micron pre-filter and 0.45-micron filter.

Initially, the 4-liter volumes were collected for TSS analysis instead of the 1-liter required by the laboratory. The extra sample volume was collected in attempt to provide a sufficient mass of filtered suspended solids required for total metals analysis. However, despite the extra sample volume, there was not enough suspended solids mass for metal analysis. As a result, the sample volume for TSS analysis returned to the standard 1-liter volume for the remaining baseflow events.

Storm Event Sampling: April 2002 – October 2002

The automated sampling and monitoring instruments were used to collect surface water samples and data during storm events. Samples were collected during six storm events (two spring, two summer, and two fall storms). Initially, storm conditions were defined as rain events greater than 1.5 inches and the sampling program was scheduled to occur over a 12-month period from May 2001 to May 2002. However, due to drought conditions experienced during that period, no storm events met the sample criteria and EPA extended the sampling program an additional 6 months, through October 2002. For the study extension period, the threshold

for a storm event was reduced to rain events of approximately 1 inch. The table below presents the dates, times and approximate size of storm events sampled.

**Storm Events Sampled
MSGRP 2001 – 2002 Surface Water Investigation**

Storm Name	Begin Date/Time of Storm Event	End Date/Time of Storm Event	Total Rainfall Measured at Reading Weather Station
April, 2002	4/25/02 15:00	4/26/02 00:00	0.97 inches
May, 2002	5/12/02 01:00	5/14/02 04:00	2.80 inches
July, 2002	7/23/02 14:00	7/24/02 01:00	1.15 inches
August, 2002	8/29/02 06:00	8/30/02 03:00	1.26 inches
September, 2002	9/23/02 23:00	9/24/02 06:00	1.12 inches
October, 2002	10/16/02 07:00	10/16/02 20:00	1.48 inches

Three stations (1, 2, and 4) in the northern portion of the Study Area were used to initiate the automated samplers. These stations were programmed so that a specified rise in stream level over a particular time period, and a rainfall rate of more than 0.01-inches of rain in 1 hour would automatically trigger start of the auto-sampler and notify TtNUS by telephone that sampling had begun. After receiving notice from these stations that sampling had been initiated, TtNUS personnel would call the remaining stations and remotely start the individual sampling programs at each station. The sampling program would continue throughout and following the storm, until a designated stage threshold on the falling limb of the hydrograph was reached and the river approached base-flow conditions, whereby TtNUS terminated the auto-sampler programs.

Samples were collected from each station at pre-set intervals throughout the storm event. The sampling intervals at Stations 1, 2, 3, 5, 6, 7, and 10 were set based on flow-weighted criteria for each station (see the table below) determined based on the flow rates and volume of flow at each station during various rain events. For example, at Station 1, a sample was collected after every 50,000 cubic feet of flow through the station. Samples were collected hourly at stations 4, 8, and 9. All of the samplers were programmed to run until all sample bottles were filled. In most cases, TtNUS personnel interrupted the auto-samplers' program to add more bottles, then re-engaged the program. This was done in order to capture the entire storm event, which for most of the storm events required more than 24 sample bottles. See Appendix 2C for additional information on the determination of sampling intervals.

**Sampling Intervals for Auto-Samplers
MSGRP 2001 – 2002 Surface Water Investigation**

Sample Station	Flow Volume or Duration Per Sample Interval
1	50,000 cubic feet
2	50,000 cubic feet
3	50,000 cubic feet
4	Hourly
5	80,000 cubic feet
6	80,000 cubic feet
7	1.46 Million gallons
8	Hourly
9	Hourly
10	1.46 Million gallons

Two types of samples were collected during storm-event sampling: composite samples and grab samples. Composite samples were collected at all stations except 4 and 8. At the composite-sample stations, the auto-sampler retrieved a 200-ml aliquot of sample at each specified sampling interval and dispensed it into a 1-liter sample bottle. Four 200-mL samples were dispensed into each 1-liter bottle. After the storm, all the sample bottles filled by the auto-sampler over the duration of the storm were manually composited into a single container and mixed. Aliquots were drawn off this single composite sample, filtered (dissolved metals fraction only), preserved, and submitted for total metals, dissolved metals, and TSS analysis.

Grab samples were collected at stations 4 and 8. At these stations, the auto-sampler retrieved an 800-ml aliquot of sample at each specified sample interval (every hour) during the storm-event and dispensed it into a 1-liter sample bottle. After the storm, the sample bottles removed from the primary sampler were divided into two sample bottles (for total metals and TSS analysis) and preserved. The samples removed from the secondary sampler were filtered (using the procedure described above for monthly base-flow sampling) and preserved for dissolved metals analyses.

Due to budgetary constraints, only a fraction of the grab samples were sent for chemical analysis. After the storm, TtNUS evaluated the storm hydrographs for each station to assist in selecting samples for analysis. Generally, every other sample collected during the rising limb of the hydrograph and the first four hours of the peak of the hydrograph was selected for analysis. Thereafter, every fourth sample was selected for analysis.

The total and dissolved metals samples from Stations 4 and 8 that were not initially selected for analysis were stored at TtNUS' offices for possible future analysis. Due to a shorter holding time, samples for TSS could not be stored for future analysis. Following evaluation of the analytical results from the initial set of samples, some of the stored samples were selected and analyzed to resolve or confirm inconsistencies or anomalies in the initial metals data. A surface water sampling summary is presented in Table 2-6.

2.2.2.3 Soil Investigations

TtNUS conducted two phases of soil sampling in the summer of 2000 to collect data to evaluate the nature and extent of soil contamination in the RI study area and support the baseline human health and ecological risk assessments. The objectives and methods of the investigations are described below.

July 2000 Investigation – Davidson Park Floodplain

The objective of this sampling effort was to gather surface soil samples from suspected depositional areas of the floodplain around Davidson Park in Winchester to investigate the presence of elevated metals in areas where floodwater may deposit sediment that has been re-suspended in the Aberjona River. Data from this sampling will be used to characterize the nature and extent of metals contamination in the Aberjona River floodplain and to supplement the Baseline Human Health Risk Assessment.

Surface soil samples were collected at 26 locations along the east, south, and west sides of the Davidson Park pond (DP01 through DP26). These locations were selected to provide representative sample locations with an emphasis on low-lying areas. A hand auger was used to collect soil from a depth of 0 to 6 inches below ground surface (bgs) at four different points close to and surrounding the sample location. The soil from the four points was then placed in a stainless steel bowl and thoroughly mixed to homogenize the sample into a composite representative of the sample location. The soil was transferred into the appropriate sample containers and shipped to off-site laboratories for analysis. All samples were analyzed for total metals; 20 percent of the samples were also analyzed for hexavalent chromium and sulfides. Davidson Park soil sample locations and analytical methods are identified on Table 2-9. Sample locations are shown on Figure 2-3d.

August/September 2000 Investigation – Properties Adjacent to the Industri-plex Site

The objective of this investigation was to collect soil samples to help define the extent of metals (arsenic, lead, and chromium) contamination in soils adjacent to the Industri-plex Site. Previous sampling efforts did not fully characterized the extent of contamination that may extend beyond the site boundaries. Data from this sampling round will be used in conjunction with previous data collected to determine the extent of contamination and support the evaluation of the human health risks.

Soil samples were collected at four properties. At most sample locations, samples were collected at three depth intervals: 0 to 12-inch, 12 to 24-inch, and 24 to 36 inches bgs. At five locations (A204, A205, A207, A609, A612), only the upper two samples were collected because of boring refusal at approximately 2 feet bgs. The sampling locations are described below:

- Area 2 – Seven soil sample locations at Dundee Park, which is located immediately west of the West Hide Pile (station A2, locations 01 – 07)
- Area 5B – Three soil sample locations at 110 Commerce Way, which is located north of the Boston Edison ROW No. 9 (station A5, locations 01 – 03)
- Area 6 – Thirteen soil sample locations at the Custodial Trust/Boston Edison property located south of the Boston Edison ROW No. 9 and extending west to the Boston and Maine Railroad (station A6, locations 01 – 13)
- Area 7 – Seven soil sample locations at the Winn Trucking property located south of the Boston Edison ROW No. 9, on the West Side of the Boston and Maine Railroad (station A7, locations 01 – 07)

At each soil sample location a hand auger was used to collect a composite sample from each depth interval. The soil from each interval was placed in a stainless steel bowl and thoroughly mixed to homogenize the sample into a composite representative of the depth interval. The soil was transferred into the appropriate sample containers and shipped to off-site laboratories for analysis. All samples were analyzed for total metals; 20 percent of the samples were also analyzed for hexavalent chromium and sulfides. Soil sample locations and analytical methods are identified on Table 2-9; sample locations are shown on Figure 2-3a.

2.2.2.4 Groundwater Investigations

This section describes the two groundwater investigations conducted by TtNUS under the MSGRP: the July 2001 MSGRP/GSIP “Split” Sampling Program and the January through April 2002 Hydrogeologic Study.

July 2001 – MSGRP/GSIP “Split” Sampling Program

The objective of the July 2001 groundwater sampling event was to collect groundwater anion/cation and total dissolved solids (TDS) data necessary to evaluate the migration mechanisms for metals in groundwater in the Northern Study Area.

Groundwater in the area was being investigated by the ISRT as part of the Final GSIP SOW Groundwater Investigation (described in Section 2.1.5.2). However, the approved scope of work for the investigation did not include analyses for the major anions and TDS. As a result, the parties agreed that EPA (via TtNUS) would obtain “split” samples from the ISRT consultants as they were sampling for other parameters. The “split” samples would be analyzed for major anions (chloride, nitrite, nitrate, phosphate, bicarbonate, sulfate) and TDS. The major cation concentrations would be obtained from the ISRT metals analyses.

TtNUS obtained 53 “split” groundwater samples plus QA/QC samples from the ISRT’s consultants while they were collecting samples for the plume geochemistry phase of their groundwater investigation as described in Section 2.1.5.2. The samples were collected from selected sampling locations on the “B”, “E”, “W”, “L”, and “H” transects established for the ISRT investigation. The “split” groundwater sampling locations and analyses details are identified on Table 2-10; groundwater sample locations are shown on Figure 2-4.

January – April 2002 MSGRP Hydrogeologic Study

TtNUS conducted a hydrogeologic study in 2002 to evaluate the potential sources of contamination in the Study Area that may represent continued risks to human health and the environment along the Aberjona River or that may have an adverse impact on the remedial actions that have been taken at the Industri-plex Site, and to collect hydrogeologic information throughout the study area to assist in the evaluation of groundwater flow patterns. The

investigation was also designed to assist in characterizing the extent of groundwater contamination on Class A Properties, and determining the possibility of de-listing portions of Class A Land from the Industri-plex Site.

Direct push technology (DPT) drilling was used in the hydrogeologic investigation to advance temporary monitoring wells and to advance groundwater-sampling devices to collect samples directly from within the DPT boreholes. Generally, the temporary monitoring wells were used to collect groundwater samples and determine the water level in the shallow aquifer and the DPT-borehole samplers were used to collect intermediate and deep aquifer samples.

The general sampling approach was to collect three groundwater samples from each sample location, one each from the shallow, intermediate, and deep zones of the overburden aquifer. However, at some locations, intermediate and/or deep samples were not collected because refusal was reached or the deeper aquifer zone(s) did not yield water at a rate sufficient to collect a representative groundwater sample. At a few locations where overburden deposits were thicker, a fourth sample was collected to better evaluate the entire saturated thickness.

The intermediate and deep aquifer groundwater samples were collected while advancing a small diameter (nominal 1-inch inside diameter) DPT boring. When the boring had been advanced to the target depth, the sampling device was deployed and the sample zone was purged and sampled in accordance with the EPA Region I Low Stress (low flow) Purging and Sampling Procedure, modified as described in Section 9 of the QAPP (TtNUS, 2002). If there was insufficient flow to collect the sample from the selected zone the sampler would be moved to a different depth(s) and additional attempt(s) would be made to collect a representative sample from the aquifer zone.

After completion of the in-borehole groundwater sampling, a second boring was advanced and a nominal 1-inch inside diameter, schedule 40 PVC, factory slotted well screen and riser were installed. Generally, the wells were screened across the water table and the well extended to a depth of approximately 10 feet below the water table. In a few wells, where the water table was close to the ground surface, the screen was set slightly lower than the top of the water table to allow for installation of an adequate seal at the ground surface. The shallow aquifer groundwater sample was collected from the temporary well using the low flow procedure referenced above. These wells would also serve as monitoring points to evaluate groundwater

flow conditions by conducting static water level measurement rounds during varying seasonal conditions. See Section 9 of the QAPP (TtNUS, 2002) for more details on well installation and groundwater sampling methods and Section 3 of this report for additional information regarding groundwater flow conditions.

The areas of investigation for the hydrogeologic study were selected based on information summarized in the Preliminary MSGRP Report (HNUS, 1997) and the TtNUS QAPP (TtNUS, 2002). The following text provides a background on these areas and describes the sampling and monitoring program for each well group. A groundwater sampling summary for all sampling locations is presented in Table 2-10. Groundwater sampling locations are shown on Figure 2-4.

Area A – Sites North of the Industri-plex Site (Sites A-4 and A-5) – Area A is located north and northwest of the Industri-plex Site, and includes several state-listed hazardous waste sites including the Olin Chemical site (Site A-4). The existing information suggests that groundwater at the Olin Chemical site is contaminated with chromium, ammonia, and chloride, and to a lesser extent with various semi-volatile organic compounds (SVOCs) and chlorinated solvents. A groundwater divide occurs at Olin and results in the groundwater flowing from the site in two different directions: northwest and southeast. The most significant contamination, dense non-aqueous phase liquid (DNAPL), is believed to migrate to the northwest.

To the east and south of the Olin Chemical site, other sites have reportedly released VOC contamination within the aquifer of southern Wilmington. It appears that some of the contamination may discharge into the East Drainage Ditch along the Massachusetts Bay Transportation Authority (MBTA) right-of-way (ROW), which discharges into the New Boston Street Drainway, Halls Brook Holding Area, and ultimately the Aberjona River. The remaining groundwater contamination appears to migrate southeast towards North Pond, in north Woburn.

Area A groundwater sampling locations were selected to maximize the potential for detecting groundwater contaminants that may be migrating into the Industri-plex study area from the north, particularly sites A-4 and A-5 (the former Ritter Trucking) identified in the Preliminary MSGRP Report (HNUS, 1997). The distribution of these sampling

points will also provide data to support the construction of water table maps of this area and the entire Study Area.

TtNUS collected groundwater samples and water level data from eight boring locations (AA01 – AA03 and AA05 – AA09) in Area A downgradient of Sites A-4 and A-5. Groundwater samples were collected from temporary shallow wells at all eight locations and from deeper zones at three of the locations. The groundwater samples were analyzed for total metals, VOCs and SVOCs.

Area C – Sites Southwest of the Industri-plex Site (Sites C-3 and C-5) – Area C is located southwest of the Industri-plex Site, west of the Halls Brook Holding Area. Existing information indicates that groundwater in this area flows toward the Halls Brook Holding Area pond where it discharges to the surface water. Two sites in this area, the 3-C Company located at 181 New Boston Street (Site C-3) and Atlantic Plywood Property on Roessler Road (Site C-5) were identified in the Preliminary MSGRP Report (HNUS, 1997) as potential continuing sources of contamination.

TtNUS collected groundwater samples and water level data from six boring locations (AC01 – AC06) in Area C, between New Boston Street and Roessler Road, and Halls Brook Holding Area to evaluate whether these sites are continuing sources of contamination to Halls Brook Holding Area and the Aberjona River. Groundwater samples were collected from shallow and intermediate aquifer zones at all six locations and from the deep zone at three of the locations. The groundwater samples were analyzed for total metals and VOCs.

Area E – Sites South of the Industri-plex Site (Sites E-1 and E-2) – Sites E-1 and E-2 are in the area of the former Mishawum Lake. Previous investigations in the area of the former Mishawum Lake bed have detected elevated concentrations of arsenic in the groundwater. These data suggest that the geochemical conditions within the former lake bed sediments may cause metals that are bound to the sediments to migrate with the groundwater.

TtNUS collected groundwater samples and water level data from seven boring locations (AE01 – AE07) in Area E: five sample locations on the east side of the Halls Brook

Holding Area and downgradient of the former Mishawum Lake and two locations upgradient of the former lake. Groundwater samples were collected from shallow and intermediate aquifer zones at all seven locations and from the deep zone at six of the locations. The groundwater samples were analyzed for total and dissolved metals, VOCs, arsenic speciation, major anions (chloride, nitrite, nitrate, phosphate, bicarbonate, sulfate), and total dissolved solids (TDS). The major cations are included in the total and dissolved metals analysis.

Area F – Sites Outside the Vicinity of the Industri-plex Site (Site F-1) – According to the Preliminary MSGRP Report, 184 drums were removed from the MBTA Property on Mishawum Road (Site F-1) in May 1979 and soil samples collected in the late 1980s contained elevated levels of metals, including the COCs chromium, lead, and mercury, and numerous SVOCs, including PAHs. In addition, urban fill materials (cinder, ash, construction debris) and animal hides were observed on the site. Based on MADEP files, no groundwater sampling information was available for the site (HNUS, 1997).

TtNUS collected groundwater samples and water level data from three boring locations (AF01 – AF03) on the east side of the MBTA right of way between Mishawum Road and I-95, down gradient of the potential source area. Groundwater samples were collected from shallow, intermediate, and deep aquifer zones at all three locations. The groundwater samples were analyzed for total metals and VOCs.

Area G – Former Landfill Area (Site G-1) – Site G-1 is located south of the former Allstate Sand and Gravel Dump, an open burning dump used for disposal of municipal and other solid waste until it was closed by order of the state in 1968. Tens of thousands of cubic yards of waste were reportedly removed from the dump in the late 1960s and moved to the Woburn Sanitary Landfill off Merrimac Street in Woburn during the development of the Woburn Industrial Park; however, soils with elevated levels of contaminants have been found on properties (such as site C-5, described above) within the former dump property. (HNUS, 1997)

TtNUS collected groundwater samples and water level data from three boring locations (AG01 – AG03) west of the south end of the Halls Brook Holding Area, adjacent to the former Mishawum Lake, to evaluate potential continuing contamination from the area

west of these borings and support the construction of a water table map of this area. Groundwater samples were collected from shallow, intermediate, and deep aquifer zones at all three locations. The groundwater samples were analyzed for total metals and VOCs.

Presidential Way – Presidential Way is located north of the East Central Hide Pile. Three borings were installed in this area to evaluate potential contaminant migration from the West and East Hide Piles. Previous investigations have identified VOCs originating from these locations. In addition, these locations were in the vicinity of the former ‘arsenic pit’.

TtNUS collected groundwater samples and water level data from three boring locations (AP01 – AP03) spaced approximately 200 feet apart along Presidential Way. Groundwater samples were collected from shallow and intermediate aquifer zones at all three locations and also in the deep aquifer zone at one location. The groundwater samples were analyzed for total metals and VOCs.

Class A Properties – Portions of Class A Land situated towards the eastern portion of the Industri-plex Superfund Site along Commerce Way and the Commerce Way Extension are being considered for de-listing from the site. The extent of groundwater contamination (e.g. toluene, benzene, and arsenic) on Class A Properties was characterized to support EPA in determining if portions of these properties should be de-listed.

TtNUS collected groundwater samples and water level data from eight boring locations (CA02 – CA09) on the west side of Class A Properties. Borings were attempted at three additional locations (CA01, CA10, CA11), but were abandoned due to repeated shallow refusals. Groundwater samples were collected from shallow, intermediate, and deep aquifer zones at five locations and only from the shallow zone at three locations. The groundwater samples were analyzed for total metals and VOCs.

Site-Wide Observation Monitoring Wells – TtNUS installed shallow monitoring wells at eight locations (MW02 – MW09) throughout the Industri-plex Site to assist in the evaluation of study area groundwater flow patterns. A boring was attempted at one

additional location (MW01), but the location was abandoned due to repeated shallow refusals. These wells were intended to be used solely to collect water level data; however, groundwater samples were collected from one location (MW04) to allow more complete evaluation of the nature and extent of contamination near the adjacent South Hide Pile.

Groundwater samples were collected from the shallow, intermediate, and deep aquifer zones at MW04. The groundwater samples were analyzed for total metals and VOCs.

2.2.3 MSGRP Northern and Southern Study Areas – EPA

EPA NERL conducted additional investigations of the Industri-plex Site and Aberjona River study areas to supplement the GSIP and MSGRP investigations conducted by others. These investigations are described in the following sections. All sample log sheets from these investigations are included in Appendix 2A, arranged by media.

2.2.3.1 EPA NERL – Supplemental Sediment and Soil Investigations

EPA NERL conducted supplemental sediment and soil investigations in the Industri-plex/Aberjona River Study Area in July and September 2002, February 2003, and March and April 2004 to fill data gaps remaining from previous investigations. The supplemental investigations included collection of surface soil and sediment samples, and sediment core samples.

The surface (0 to 6 inch depth interval) sediment and soil samples were collected principally to support the evaluation of potential human and ecological risks. These samples were obtained from locations accessible to humans and/or animals. The surface sediment samples were generally collected at locations with water shallower than 2 feet deep; however, six surface sediment samples (AJRW01 - AJRW06) were collected in deeper water considered to be accessible to aquatic receptors only. The sediment core samples, obtained in 1-foot intervals to a depth of 4 feet, were collected to better define the depth of contaminated sediment. All the soil and sediment samples collected will be used to assist in understanding of the nature and extent of contamination.

In general, the EPA NERL sediment and soil sampling was conducted using the same methods followed by TtNUS in the MSGRP RI study area investigations described in Section 2.2.2. The only significant difference was that EPA's February 2003 investigation included collection of sediment core samples to a depth of 4 feet bgs; only surface sediment samples had been collected in previous investigations.

Surface sediment samples were collected from a depth interval of 0 to 6 inches bgs. The samples were collected using either a hand tool such as a stainless-steel scoop or auger, or an Eckman grab sampler. In general, hand tools were used at locations where little or no standing water was present and Eckman samplers were used at submerged locations. The Eckman samplers were deployed on a rope line over the side of a small boat or attached to a pole and used while wading.

For both surface sediment and sediment core samples, the sediment was placed into a stainless steel bowl and thoroughly mixed to homogenize the sample. Any excess water was carefully decanted to avoid discarding sediment fines and the homogenized sediment was transferred to the appropriate sample containers.

Sediment core samples were collected in 1-foot intervals from the ground surface to a depth of approximately 4 feet. The core samples were collected using hand augers. The auger was advanced inside of a 3-inch diameter PVC casing and manually driven to ensure that the borehole remained open between samples.

Soil samples were collected from a depth of 0 to 6 inches below ground surface using a hand auger. Soil was collected from several points close to the sample location to ensure collection of adequate volume. The soil from the different points was then placed in a stainless steel bowl and thoroughly mixed to homogenize the sample into a composite representative of the sample location. The soil was then transferred to the appropriate sample containers.

Details of the individual investigations are described below.

July 2002 Sediment Investigation

Surface sediment samples were collected from several locations in the Aberjona River study area in July 2002 to support the baseline human health and ecological risk assessments. The samples were collected from a depth of 0 to 6 inches using the methods described above.

Sediment samples were collected from the following areas:

- Halls Brook Holding Area (station HB02, locations 11 – 17) – seven locations in the wetland area on the east side of the HBHA
- Halls Brook Holding Area (Station HB03, locations 11 – 17) – seven locations in the wetland area on the west side of the HBHA
- Aberjona River (Station AR, locations 01 – 06) – six locations in the Aberjona River channel before the confluence of the HBHA
- Boston Edison Right-of-Way (Station BE, locations 04 – 11, except 07) – seven locations in drainage channels on the Boston Edison Right-of-Way (BE-07 location cancelled)
- Proposed boardwalk/nature trail (Station BW, locations 01 – 05) – five locations along the path of the proposed boardwalk and nature trail in the Wells G&H wetland
- Wells G&H Wetland near junk yard (Station JY, locations 06 – 15) – 10 locations in the wetland adjacent to the automotive junk yard at Aberjona Auto Parts, north of Salem Street
- Cranberry Bog (Station CB-04, locations 1 – 10) – 10 locations in bog and marsh areas in the central portion of the Cranberry Bog Conservation Area
- Cranberry Bog (Station CB-06, locations 01 – 10) – 10 locations in channels in the southern portion of the Cranberry Bog Conservation Area
- Cranberry Bog (Station CB-07, locations 01 – 06) – six locations in bog and marsh areas within the Cranberry Bog
- Leonard Pool (Station LP, locations 01 – 10) – 10 locations in the Aberjona River near Leonard Pool

All samples were analyzed for total metals and total organic carbon. Samples from the ‘JY’ locations were also analyzed for PCBs since PCBs were found in surface soils at the Aberjona

Auto Parts site (RETEC, 1994). Sample locations and analyses performed are identified on Table 2-5. Sediment sample locations are shown on Figures 2-7a, 2-7b, 2-7c, and 2-7e.

July 2002 Soil Investigation

Soil samples were collected from several locations in the Southern Study Area in July 2002 to support the baseline human health and ecological risk assessments. The samples were collected from suspected depositional areas within the floodplain to investigate the presence of elevated metals in areas where floodwater may have deposited suspended contaminated sediments into upland areas. The surface soil samples were collected from a depth of 0 to 6 inches bgs using the methods described in Section 2.2.3.1. Samples were collected from the following areas:

- Halls Brook Holding Area (Station HB04, locations 01 – 10) – 10 locations in the mid-portion of the HBHA, along a dirt access road east of the HBHA wetland
- Boston Edison Right-of-Way (Station BSO, locations 01 – 04) – four locations on the embankment above drainage channels on the Boston Edison Right-of-Way
- Salem Street Residence (Station WSS, locations 01 – 05) – five locations on a residential property in the Aberjona River floodplain, immediately west of the Salem Street bridge
- Cranberry Bog (Station CB-05, locations 1 – 10) – 10 locations off a dirt foot path on the west side of the Cranberry Bog Conservation Area
- Danielson Park (Station DAP, locations 01 – 05) – five locations along the bank of the Aberjona River, across from Danielson Park, downstream of the Washington Street Bridge

All samples were analyzed for total metals and total organic carbon. The sample locations and analyses performed are identified on Table 2-9. Soil sample locations are shown on Figures 2-3a, 2-3b, and 2-3c.

September 2002 Sediment Investigation

Sediment samples were collected from several locations in the Aberjona River study area in September 2002 to fill data gaps for the baseline human health and ecological risk

assessments. The samples were collected from a sediment depth interval of 0 to 6 inches bgs using the standard methods described in Section 2.2.3.1. Samples were collected from the following locations:

- Boston Edison right-of way (Station BE, locations 01 through 03) – three locations along drainage channels in the Boston Edison right-of-way
- Normac Road (Station NR, locations 01 – 05) – five locations in the northern portion of the Wells G&H wetland off Normac Road
- Kraft Foods south of Montvale Ave (Station KFSD, locations 01 – 10) – 10 locations in the Aberjona River adjacent to the Kraft Foods well field
- Leonard Pool (Station LP, locations 11 – 15) – five locations at Leonard Pool in Winchester (4 locations within the pool area and one [LP-11] at the dam outside the pool)

All samples were analyzed for total metals and total organic carbon. Sample locations and analyses performed are identified on Table 2-5. Sediment sample locations are shown on Figures 2-7a, 2-7b, 2-7d, and 2-7e.

September 2002 Soil Investigation

Surface soil samples were collected from two areas in September 2002 to fill data gaps for the baseline human health and ecological risk assessments. The samples were collected from suspected depositional areas of the floodplain to investigate the presence of elevated metals in areas where floodwater may have deposited re-suspended sediment. The soil samples were collected from a depth of 0 to 6 inches bgs using the methods described in Section 2.2.3.1. Samples were collected from the following locations:

- Normac Road (Station NR, locations 16 – 20) – five locations along the bank of the Aberjona River in the northern portion of the Wells G&H wetland off Normac Road
- Kraft Foods south of Montvale Ave (Station KFSO, locations 01 – 10) – 10 locations along the east bank of the Aberjona River in the Kraft Foods well field

All samples were analyzed for total metals and total organic carbon. Sample locations and analyses performed are identified on Table 2-9. Soil sample locations are shown on Figures 2-3b and 2-3c.

February 2003 Sediment Core Investigation

Sediment core samples were collected from 13 locations throughout the Industri-plex/Aberjona River study area in February 2003 to better evaluate the depth of contaminated sediment in the study area. Four samples were collected from each location, in 1-foot intervals from the sediment surface to a depth of 4 feet. The samples were collected and processed using the methods described in Section 2.2.3.1. Samples were collected from the following locations:

- Halls Brook Holding Area (SC-01 – SC04) – four locations in the HBHA wetlands and wetland ponds
- Wells G&H Wetland (SC05, SC06, SC07) – three locations in wetland near location of proposed boardwalk
- Salem Street ponded area (SC08) – one location in a ponded area of the Aberjona River near the Salem Street West (residence) sample locations
- Cranberry Bog (SC09, SC10) – two locations in wetland areas within the Cranberry Bog Conservation Area
- Davidson Park (SC11) – one location in pond at Davidson Park
- Judkins Pond (SC12) – one location in Judkins Pond
- Upper Mystic Lake (SC13) – one location in the upper forebay of the Upper Mystic Lake

All samples were analyzed for total metals and total organic carbon. Sample locations and analyses performed are identified on Table 2-5. Sediment core locations are shown on Figures 2-7a through 2-7g.

March 2004 Sediment Investigation

- Sediment samples were collected at six locations (AJRW01 – AJRW06) in a ponded area of the Aberjona River between Bacon Street and Mystic Valley Parkway in Winchester in March 2004 to characterize contamination in this depositional area

and provide supplemental data for the baseline ecological risk assessment. The samples were collected in deep water locations considered to be accessible to aquatic receptors, but not generally accessible to humans. Water depths at the sample locations ranged from 1.5 feet to 3.75 feet, with all but one sample collected from water deeper than 2 feet. The samples were collected from a sediment depth interval of 0 to 6 inches bgs using the standard methods described in Section 2.2.3.1.

All samples were analyzed for total metals. Sample locations and analyses performed are identified on Table 2-5. Sediment core locations are shown on Figure 2-7f.

April 2004 Sediment and Soil Investigation

Surface sediment and soil samples were collected from the southern shoreline of a ponded area of the Aberjona River between Bacon Street and Mystic Valley Parkway in Winchester in April 2004 to characterize contamination in the shoreline sediments and the floodplain adjacent to this depositional area. The data were collected for use in the baseline human health and ecological risk assessments and in evaluating the nature and extent of contamination. The samples were collected from a depth interval of 0 to 6 inches bgs using the standard methods described in Section 2.2.3.1. The following samples were collected:

- Aberjona River Winchester shoreline sediment samples (AJRW07 – AJRW23 odd numbers) – nine locations along the southern shoreline of the ponded area between Bacon Street and the Mystic Valley Parkway. Water depths at all these sediment sample locations were less than 2 feet.
- Aberjona River Winchester floodplain soil samples (AJRW08 – AJRW24 even numbers) – nine locations along the southern bank of the ponded area between Bacon Street and the Mystic Valley Parkway. Note that sample location AJRW12R was selected to replace location AJRW12, which was judged to be a poor location due to its close proximity to a manhole. The sample from station AJRW12 was not retained for analysis.

All samples were analyzed for total metals. Sample locations and analyses performed are identified on Table 2-5. Sediment core locations are shown on Figure 2-7f.

2.2.3.2 EPA ORD – Industri-plex Site Arsenic Natural Attenuation Study

EPA Office of Research and Development (ORD) conducted a field investigation in several phases from October 1999 to September 2001 to support an assessment of arsenic contamination and migration within the Northern Study Area. The objectives of the study were to 1) determine migration mechanisms controlling arsenic transport at the Industri-plex Site and study area, 2) evaluate the potential role of natural attenuation processes in mitigating arsenic transport from the site and study area, and 3) provide guidance for determining reasonable, cost-effective treatment technologies for the Aberjona River.

The field investigation included collection of groundwater, surface water, and sediment samples from the Industri-plex Site and study area. Sample collection efforts focused on characterization of arsenic migrating from site groundwater to the surface water and sediment in the HBHA. Details of the field investigation, study methodology, and results are presented in the study report (Draft *Project Report: Natural Attenuation Study; Groundwater, Surface Water, Soil, and Sediment Investigation; Industri-plex Superfund Site; Woburn, Massachusetts*. Robert Ford, EPA ORD, September 2004) in Appendix 2D. Study results are also discussed and used in the evaluation of contaminant fate and transport (Section 5 of this report). The chemical characterization data from this investigation will not be used in evaluating the nature and extent of contamination or for determining risk because the sampling, analytical, and data validation procedures used in the investigation differ from those used in the other study area investigations. As a result, these samples are not included in the tables or figures in Section 2.

2.2.3.3 Aberjona River Sediment Arsenic Bioavailability Study

EPA and TtNUS collected sediment samples in August 2002 for use in an arsenic bioavailability study performed for EPA by researchers from the University of Missouri at Columbia and the Syracuse Research Corporation of Denver Colorado. The objective of the study was to obtain site-specific data on the relative bioavailability of arsenic in study area sediments to improve the accuracy and decrease uncertainty in human health risk calculations.

For this investigation, a total of 12 sediment samples were collected from previously sampled locations in four portions of the MSGRP RI study area: HBHA, the Wells G&H wetland, the Cranberry Bog Conservation Area, and Davidson Park. The samples were collected to cover a

range of arsenic concentrations and to provide reasonable spatial representativeness within the study area.

The samples were collected as near to the previous sampling locations as possible. All samples were collected from a sediment depth interval of 0 to 6 inches using a hand tool such as a stainless-steel scoop. The sediment was placed directly into individual 2-gallon plastic buckets and sent to the researchers for characterization and use in the bioavailability study.

Details of sample preparation and analysis, as well as study objectives, methodology and results are presented in the Aberjona River baseline risk assessments (M&E, 2004) (*Relative Bioavailability of Arsenic in Sediments from the Aberjona River*, Casteel, et al, December 2002). The study results were used in the human health risk assessment (Section 6 of this report) to estimate arsenic exposure doses. A copy of the report is also provided as Appendix 6K. Because the samples were collected and characterized using methods designed specifically for the purposes of the bioavailability study, the characterization data from these samples will not be used in quantitative evaluation of the nature and extent of contamination or in the calculation of exposure point concentrations in the risk assessments. As a result, these samples are not included on tables and figures in Section 2.

2.3 Additional Studies

In addition to the studies conducted in support of the MSGRP RI, TtNUS reviewed and used information from a variety of additional investigations in preparing the RI. This section identifies significant documents reviewed and used in planning and preparing the RI.

2.3.1 Industri-plex Site Investigations

Several investigations were conducted on behalf of the ISRT and individual Industri-plex Site land owners that were not part of the GSIP investigations. This section identifies the significant studies used in preparing the RI.

Investigations supporting the Industri-plex Site ROD (OU1) – The initial remedial investigation and feasibility study for the Industri-plex Site, used to support the 1986 ROD, was conducted by Stauffer Chemical Company between 1982 and 1985. The

investigation was undertaken voluntarily by Stauffer as part of a Consent Order with the EPA and Massachusetts DEQE signed in May 1982. The methods and results of the investigations are presented in the following reports:

- *Woburn Environmental Studies Phase I Report, Volume 1 Environmental Assessment* (Stauffer, April 1983)
- *Woburn Environmental Studies Phase II Report, Volume 1 Remedial Investigation* (Stauffer, August 1984)
- *Woburn Environmental Studies Phase II Report, Volume 2 Feasibility Study* (Stauffer, April 1985)

Investigations supporting the design of the Soil Cover Remedy and Interim Groundwater Remedy – Several reports and studies were completed on behalf of the ISRT in support design of the soil cover remedy and proposed interim groundwater remedy. These reports included:

- *30, 60, 90, and 100 Percent Design Reports for Soil Cover Remedy* (Golder, 1990-1991)
- *Pre-Design Investigation Task 1 GW-1 Plume Delineation Interim Final Report Industri-plex Site Woburn, MA* (Golder, 1991a)
- *Pre-Design Investigation Task GW-2 Hydrogeologic Characterization for the Extraction/Recharge System Interim Final Report Industri-plex Site Woburn, Massachusetts* (Golder, 1990)
- *Pre-Design Investigation Slug Test Report Industri-plex Site Woburn, MA.* (Golder, 1991b)
- Golder Associates Inc. 1991c. *Aquifer Pumping Test Industri-plex Site Woburn, MA* (Golder, 1991c)

2.3.2 Wells G&H Study Area Investigations

Many environmental studies have been conducted within and around the Wells G&H Superfund Site. These studies have included investigations to evaluate nature and extent of contamination and risks to humans and ecological receptors. Several of these investigations have been evaluated as part of the MSGRP RI. The more significant studies reviewed are as follows:

- “Baseline Human Health and Ecological Risk Assessment, Southwest Properties, Wells G&H Superfund Site, Operable Unit 2, Woburn, Massachusetts”; TRC Environmental Corporation, March 2004.
- “Wells G&H Site Central Area Remedial Investigation, Phase 1A Report”; GeoTrans, Inc. and RETEC. February 14, 1994.
- “Technical Memorandum – Possible Effects of Arsenic and Heavy Metal Sediment and Surface Water on Future Potable Water Supply Development on the Central Area Aquifer at the Wells G&H Superfund Site”; TRC Environmental Corporation; January 2005
- “Data Summary Report for the Former Drum Disposal Area, Wells G&H Superfund Site, Operable Unit 1 – Olympia Property, Woburn, Massachusetts”; TRC Environmental Corporation. December 2002.
- “Area of Influence and Zone of Contribution to Superfund Site Wells G and H, Woburn, Massachusetts”; United States Geological Survey. Water-Resources Investigations Report 87-4100; Boston, Massachusetts; 1987.
- “Hydrogeology and Simulation of Ground-Water Flow at Superfund-Site Wells G and H, Woburn, Massachusetts”; United States Geological Survey. Water Resources Investigations Report 87-4059; Boston, Massachusetts; 1989.
- “Expanded Trip Report for John J. Riley, Woburn Massachusetts”; Weston Solutions, Inc.; September 2004

2.3.3 Other Relevant Investigations

Throughout the MSGRP RI Study Area, environmental investigations have been conducted to evaluate the nature and extent and fate and transport of contaminants at MADEP-listed sites and at sites investigated by EPA. Several of these site investigation reports were evaluated as part of the MSGRP RI. Some of the key studies reviewed are as follows:

- HNUS, 1997. *Preliminary Multiple Source Groundwater Response Plan Report*. EPA Work Assignment No. 11-1L07, Contract No. 68-W8-0117. Halliburton NUS Corporation. August 1997.
- TtNUS, 2003. Draft Preliminary MSGRP Supplemental Report - Southern Area. *EPA Work Assignment No. 116-RICO-0107, Contract No. 68-W6-0045. Tetra Tech NUS, Inc. June 2003.*

- Weston, 1998a. *Final Site Inspection Prioritization Report for Ritter Trucking Co., Wilmington, Massachusetts*. Roy F. Weston, Inc. September 25, 1998.
- Weston, 2001. *START Expanded Site Inspection. J.O Whitten Co. (former), Winchester, Massachusetts*. Roy F. Weston, Inc. March 2001.
- “Supplemental Phase II Report, Wilmington, Massachusetts Site, Olin Corporation”; Smith Technology Corporation, et al; June 1997
- “Report on the Closure and Capping of the City of Woburn’s Landfill”; MADEP, 2002.
- “Results of Phase II Field Investigation, 100 Eames Street, Wilmington, Massachusetts, DEP Case No. 3-0470, Waiver Submittal”; GZA GeoEnvironmental; March 1993
- “Results of Additional Sampling Analysis, Raffi & Swanson Property, Wilmington, Massachusetts, DEP Case No. 3-0470, Waiver Submittal”; GZA GeoEnvironmental; March 1994
- Final Site Inspection Prioritization Report For New England Resins & Pigments, Woburn, Massachusetts”; Roy F. Weston, Inc.; August 1998

2.3.4 MIT – Aberjona Watershed Arsenic Studies

Several researchers from the Massachusetts Institute of Technology (MIT) have conducted studies of historical contamination and contaminant migration in the Aberjona River Watershed. Several MIT research publications have been reviewed to assist in planning the RI field investigations and evaluating RI data. Relevant documents reviewed for the RI include:

- “The History of Leather Industry Waste Contamination in the Aberjona Watershed: A Mass Balance Approach.” John Durant, Jennifer Zemach, and Harold Hemond. Civil Engineering Practice. 5(2):41-66. 1990.
- “Speciation and Fate of Arsenic in Three Lakes of the Aberjona Watershed.” Anna C. Aurillio, Robert P. Mason, and Harold F. Hemond. Environmental Science and Technology. 28: 577-585. 1994.
- “Metal Transport in the Aberjona River System: Monitoring, Modeling, and Mechanisms.” Helena Solo-Gabriele. Ph.D. dissertation, 1995.
- “A Method to Assess the Ecological Integrity of Urban Watersheds that Integrates Chemical, Physical and Biological Data.” Catriona Elizabeth Rogers. Ph.D. dissertation, 1998.

- “Isotopically Mapping Multiple Lead Sources on an Urban Watershed Using a Rapid Assessment Method.” Daniel J. Brabander, Rachel H. R. Stanley and Harold F. Hemond. 2001.
- “Sources and Distribution of Arsenic in the Aberjona Watershed, Eastern Massachusetts.” Anna C. Aurilio, John L. Durant, Harold F. Hemond and Michele L. Knox. *Water, Air, and Soil Pollution*. Vol. 81:265 – 282. 1995.
- “Relative Bioavailability of Arsenic in Sediments from the Aberjona River” Stan W. Casteel, Tim J. Evans, William J. Brattin, Angela M. Wahlquist. Syracuse Research Corporation, December 2002.
- “Industrial History, Mutagenicity, and Hydrologic Transport of Pollutants in the Aberjona Watershed.” M.S. Thesis, Massachusetts Institute of Technology, Cambridge, Massachusetts, John L. Durant. February 1991.
- “The Distribution and Depositional History of Metals in Surface Sediments of the Aberjona Watershed.” M.S. Thesis, Massachusetts Institute of Technology, Cambridge, Massachusetts, Michele Leigh Knox. September 1991.
- “Fracture Flow as Influenced by Geologic Features in the Aberjona Valley, Massachusetts.” M.S. Thesis, Massachusetts Institute of Technology, Cambridge, Massachusetts, Daniel McBrearty, September 1994.
- “Metal Transport in the Aberjona River System: Monitoring, Modeling, and Mechanisms.” Ph.D. Thesis, Massachusetts Institute of Technology, Cambridge, Massachusetts, Helena Solo-Gabriele, 1995.
- “Microbe Grows by Reducing Arsenic”. Nature 351:750. 1994 In: Massachusetts Institute of Technology 1994-1995 Research Progress MIT Superfund Hazardous Substances Basic Research Program P42 ES04675; Ahmann, D., A. L. Roberts, L. R. Krumholz, and F. M. M. Morel
- “Arsenic in the Aberjona Watershed”. M.S. Thesis, Massachusetts Institute of Technology, Cambridge, Massachusetts, A.C. Aurilio, September 1992.
- “Characterization of the Physical and Engineering Properties of the Aberjona Wetland Sediment”. M.S. Thesis, Massachusetts Institute of Technology, Cambridge, Massachusetts, J.L. Bialon, J.L., May 1995.
- “A Survey of Industrial Wastes of the Atlantic Gelatin Company”. M.S. Thesis, Massachusetts Institute of Technology, Cambridge, Massachusetts, R.H. Lubker and D.J. Halpin 1951.

- “Piezocone Mapping, Groundwater Monitoring, and Flow Modeling in a Riverine Peatland: Implications for the Transport of Arsenic”. Ph.D. Thesis, Massachusetts Institute of Technology, Cambridge, Massachusetts; P.J. Zeeb August 9, 1996.

3.0 PHYSICAL CHARACTERISTICS OF THE STUDY AREA

This section presents a summary of the physical characteristics of the MSGRP RI Study Area. It includes a discussion of surface features and land use, geology and hydrogeology, surface water hydrology, wetlands and floodplains, and climate and meteorology. The physical characteristics of the Northern Study Area are based on the MSGRP and GSIP investigations required by the Industri-plex ROD. These investigations included collection of groundwater, surface water, sediment, and soil data. The physical characteristics of the Southern Study Area are based on the Aberjona River Study, required by the Wells G&H ROD. This study included collection of surface water, sediment, and floodplain soils data but did not include geologic and hydrogeologic investigations.

3.1 Surface Features and Land Use

Surface features and land use, including details on the surface topography, water bodies, land use, development, zoning, and industrial and manufacturing operations, are described in this section.

3.1.1 Surface Topography

The general surface topography of the MSGRP RI Study Area decreases in elevation gradually from north to south. Higher ground surface elevations are located along the west and east borders of the study area; in the central portion of the study area, where the Aberjona River is located, the ground surface elevation is lower and relatively flat. The surface topography reflects a trough shape due to the north to south oriented buried bedrock valley, a remnant of the pre-glacial Aberjona River valley. The higher topographic elevations to the east and west correspond to the walls of the buried bedrock valley.

3.1.1.1 Northern Study Area

The Northern Study Area consists of higher topographic elevations along its east side (adjacent to I-93) and to the west (along New Boston Street). Bedrock outcrops are present in these topographic high areas. The central portion of the Northern Study Area is relatively flat and is at an approximate ground surface elevation of 18 feet (USGS Topographic Map for Reading

Quadrangle, 1987). The four hide piles located in the Northern Study Area are areas of man-made highs (see Figure 1-4). The West and East Hide Piles are located to the west and east of South Pond; both hide piles are approximately 40 feet above the ground surface. The East Central Hide Pile, located north of Atlantic Avenue, is the largest hide pile while the South Hide Pile, located south of the Atlantic Avenue Drainway, is the smallest.

3.1.1.2 Southern Study Area

The Southern Study Area consists primarily of the Aberjona River and its floodplain, which are located in low topographic areas. The surface topography of the Southern Study Area is relatively flat and is at a surface elevation of approximately 15 feet.

3.1.2 **Surface Water Bodies and Wetlands**

The MSGRP RI Study Area is located within the Aberjona River Watershed. The Aberjona River is the primary river system in the Aberjona River Basin and has a 65-km² drainage area (Solo-Gabriele, 1995). The river flows through Woburn and Winchester, terminating in Winchester where it discharges into the Mystic Lakes. The characteristics and hydrology of the Aberjona River are discussed in greater detail in Section 3.3.1. The other water bodies in the MSGRP RI Study Area are part of the Aberjona River system.

Portions of the MSGRP RI Study Area are located in the 100-year flood plain of the Aberjona River as shown on Figures 2-3a to 2-3e. The low-lying areas along the river frequently experience flooding due to increased storm water contributions from developed and paved areas, causing the Aberjona River to exceed its flow capacity. As a result, water levels top the river's banks, and storm drains and pipes overflow (CDM, 1999).

3.1.2.1 Northern Study Area

Water bodies located in the Northern Study Area include: the North and South Ponds, Halls Brook, Halls Brook Holding Area (HBHA), Phillips Pond, Atlantic Avenue Drainway, and the East Drainage Ditch. With the exception of Halls Brook, all of these water bodies were either modified or created for flood storage capacity during development of the area. The HBHA consists of a large pond, referred to as the HBHA Pond, three smaller ponds, and wetlands. The HBHA

Pond is at the northern end of the HBHA; the three smaller ponds are south of the HBHA Pond. The HBHA wetlands begin just south of the HBHA Pond, surround the three small ponds, and continue south to Mishawum Road. The HBHA is discussed in greater detail in Section 3.4.1. The Northern Study Area also includes the Created Wetlands, a compensatory wetland created as part of the Industri-plex soil remedy. It receives a portion of the flow from the South Pond and discharges to the Atlantic Avenue Drainway. Other small wetland areas are located along the Aberjona River throughout the Northern Study Area (see Figure 1-1). The 100-year flood plain is adjacent to the water bodies described above (Figures 2-3a through 2-3e).

3.1.2.2 Southern Study Area

Surface water bodies in the Southern Study Area include a small pond in Davidson Park, Leonard Pool, Judkins Pond, Mill Pond, Wedge Pond, and the Mystic Lakes. Most of these ponds are small water bodies along the river (Figure 1-1). The outlet from Wedge Pond flows as a tributary to the river. The Aberjona River discharges into the Upper Mystic Lake, a relatively large surface water body. Two embayments, the Upper and Lower Forebays, were created in 1864 when the north end of the Upper Mystic Lake was dammed. The Upper Forebay covers 2.5 acres and is approximately 6 feet deep, while the Lower Forebay covers 14.5 acres and is approximately 8 feet deep. The Upper Mystic Lake covers approximately 12.6 acres, with a mean depth of 48 feet and a maximum depth of 90 feet. It flows into the Lower Mystic Lake, which covers approximately 111 acres, and has a mean depth of 33 feet and a maximum depth of 79 feet (TtNUS, 2003).

The entire Southern Study Area (the Aberjona River and its floodplains) lies in the 100-year floodplain; wetland areas adjacent to the Aberjona River are scattered throughout the Southern Study Area. Significant wetland areas include the Wells G&H wetland and the Cranberry Bog Conservation Area (CBCA) wetland. These two areas are described in greater detail in Sections 3.4.2 and 3.4.3, respectively.

3.1.3 **Land Use and Zoning**

Various types of land use are found in the MSGRP RI Study Area. Predominant physical features include highways, streets, paved areas, commercial and industrial properties, and open space. Significant development has occurred throughout the study area. Development and land

use in the Northern and the Southern Study Areas are discussed briefly below, and in greater detail in Section 1.3.

3.1.3.1 Northern Study Area

Development and industrial activities in the MSGRP RI Study Area have occurred primarily in the Northern Study Area. The major physical features now present in the area include: East Central Hide Pile, East Hide Pile, West Hide Pile, South Hide Pile, Boston Edison Right of Way, HBHA, Created Wetland, and major roads and highways including I-93, I-95, Atlantic Avenue, Commerce Way, and Presidential Way (Figure 1-4). The majority of the highly developed Northern Study Area is paved. Areas that are not paved include the HBHA and the Boston Edison Company (BECO) right-of-way (ROW). The BECO (now NStar) ROW enters the study area from the upper portion of Merrimac Street, intersects the mid-portion of New Boston Street and terminates at the mid-portion of Commerce Way (Figure 1-4).

The Northern Study Area consists of numerous active commercial and light industrial businesses as well as a regional transportation center. The majority of the study area is zoned for commercial and industrial use. The HBHA is an undeveloped area designated on the City of Woburn zoning map as open space. The primary industries located in the Northern Study Area include general manufacturing, machine shops, printing, and instrumentation (Harris, 2002). Current and historical land use is discussed in greater detail in Section 1.3.1.

3.1.3.2 Southern Study Area

The entire Southern Study Area is undeveloped land since the area is defined as the Aberjona River and its associated floodplains and wetlands. The land use in areas immediately surrounding the undeveloped portions of the Aberjona River and associated floodplains and wetlands includes residential, business, light commercial and industrial areas. Current and historical land use is discussed in greater detail in Section 1.3.2.

3.2 Geology

This section describes the regional and study area bedrock geology, overburden geology, and hydrogeology. The discussion of regional geology encompasses the entire Aberjona River

Watershed. The study area discussion focuses on the geology of the Northern Study Area, primarily the Industri-plex Site and areas immediately adjacent to I-95. As previously noted, geologic and hydrogeologic studies were not conducted in the Southern Study Area as part of the MSGRP RI. Groundwater was not included as a media of concern in the Aberjona River Study as OU-3 was described in the Wells G&H ROD. Therefore for the purposes of the MSGRP RI, the Southern Study Area bedrock geology, overburden geology, and hydrogeology are represented by the regional geology discussion. Information on the geology and hydrogeology of the Wells G&H area is available from studies conducted for the other Wells G&H operable units, e.g. Geotrans, 1994; RETEC, 1994; and NUS, 1986. A technical memorandum completed for EPA in 2004, "Possible Effects of Arsenic and Heavy Metal Contaminated Sediment on Future Potable Water Development in the Central Area Aquifer" (TRC, 2005), presented a limited discussion of the geology and hydrogeology in the area of Wells G&H. This technical memorandum is included in this report as Appendix 5B.

3.2.1 Regional Geology

This section includes a discussion of the bedrock geology, overburden geology, and hydrogeology throughout the Aberjona River Watershed. The information presented is a compilation of data from a number of investigations conducted in the region.

3.2.1.1 Regional Bedrock Geology

Bedrock identified in the region is a crystalline igneous rock, predominately diorite and gabbro of the Proterozoic age, but also includes granite, granodiorite, quartzite, and schist (Zen et al., 1983). The bedrock types present throughout the Aberjona Watershed are shown on Figure 3-1.

The most pronounced bedrock feature in the Aberjona River Watershed is a buried bedrock valley. This bedrock valley begins in southern Wilmington and terminates under Fresh Pond in Cambridge, MA. Due to glacial advance and retreat, the bedrock valley has been scoured and abraded forming a U-shaped trough structure which has been filled in with stratified drift deposits (Chute, 1959). Based on surface topography, buried tributaries that were connected to the pre-glacial river exist beneath Horn Pond and Horn Pond Brook, two surface water features in the region (Chute, 1959).

Two major faults, the Walden Pond Fault and the Mystic Fault, are associated with the bedrock of the watershed (McBrearty, 1994). The Mystic Fault trends northeast 40° and passes through the Aberjona River bedrock valley and also through the Industri-plex Site. The Walden Pond Fault is a longitudinal fault also trending northeast and located to the south of the Industri-plex and Wells G&H Sites (approximately 1 mile southeast of the Wells G & H site). Fractures within bedrock are commonly observed along fault zones. The locations of the Mystic and Walden Pond Faults are shown on Figure 3-1.

3.2.1.2 Regional Overburden Geology

The overburden of the region is comprised of glacial deposits and post-glacial surficial deposits. The glacial deposits are classified as till and stratified drift. Post-glacial materials that overlie the glacial stratified drift and till deposits include peat, stream and swamp deposits, and artificial fill. The bedrock topography largely controls the location and thickness of the overburden deposits, with the thickest deposits corresponding to the deepest parts of the bedrock valley in the central portion of the watershed (Flanagan, et al., 1999). The till, stratified drift, and post-glacial surficial deposits in the region are described below

Till Deposits

Till deposits overlie the bedrock in some areas but are discontinuous throughout the bedrock valley (NUS, 1986; Chute, 1959). Occasionally till deposits are located at the base and along the walls of the bedrock valley, but most frequently till deposits are located at high bedrock elevations (Flanagan, et al., 1999). The till deposits observed within the region include ablation till, resulting from stagnant or inactive ice melting faster than the glacier was retreating, and also basal or lodgment till, resulting from an actively retreating glacier melting and releasing debris at the base of the glacier. The ablation till deposits consist of lenses of sorted sands and gravels. Basal till deposits consist of a poorly sorted, dense, compact mixture of clay, silt, sand, gravels, and boulders.

Stratified Drift Deposits

The stratified drift deposits are the most extensive overburden deposits of the region. They can be generally separated into four stratigraphic layers. The uppermost layer is comprised of a

mixture of sand, silt, clay, and peat deposits that ranges in thickness from 0 to 30 feet. The second, or intermediate layer, is comprised of coarse sand that ranges in thickness from 10 to 50 feet. The third layer is comprised of coarse sand and gravel, ranging in thickness from 20 to 50 feet. The lowermost layer, located in the deepest portions of the bedrock valley, is comprised of fine-grained sand and silt and can be up to 60 feet thick (de Lima and Olimpio, 1989). These deposits fill the bedrock valley and are generally not present in areas where bedrock is near the ground surface.

Post-Glacial Surficial Deposits

Recent surficial deposits of artificial fill, topsoil, peat, and stream and swamp deposits overlie the glacial deposits at various locations throughout the region. The peat and stream and swamp deposits are generally located adjacent to the Aberjona River and at low topographic areas surrounding the river. These deposits consist of interbedded silty peat, sandy peat, and organic silts (Flanagan, et al., 1999). Artificial fill deposits of sand and gravel and topsoil deposits are discontinuously scattered throughout the region.

3.2.1.3 Regional Hydrogeology

This section presents a discussion of regional hydrogeology, including details on the regional bedrock aquifer, the regional overburden aquifer, and regional groundwater discharge and recharge areas.

Regional Bedrock Aquifer

The regional bedrock aquifer is composed of crystalline igneous bedrock which typically has a low porosity and a low primary permeability. The porosity of crystalline rock generally ranges from 0 to 5 percent for dense rock and from 0 to 10 percent for fractured rock. Due to the typically low porosity and permeability values of the rock, water transport is conducted only through joints and fractures (Fetter, 1994). Bedrock fractures are primarily located in the upper portions of the regional bedrock where the bedrock is weathered. Porosity values reported for weathered crystalline rock can range from 34 to 54 percent (Fetter, 1994). Fractures in bedrock are less common with depth, resulting in low aquifer yields. A USGS study noted that yields from bedrock wells in the region range from less than 1 gallon per minute (gpm) in areas with

small and poorly interconnected fractures to greater than 100 gpm in areas where bedrock fractures are numerous and interconnected (Delaney and Gay, 1980). The study found the median yield of bedrock wells within the region to be 10 gpm.

Regional Overburden Aquifer

The main water-bearing hydrogeologic unit is the regional overburden aquifer, which is composed of stratified drift deposits. The stratified drift deposits located in the Aberjona River watershed generally are highly transmissive, ranging from 1,400 to 4,000 ft²/day (Delaney and Gay, 1980). The Aberjona River valley aquifer system is considered to be more productive than the other aquifer systems in the northeastern Massachusetts coastal drainage basins (Delaney and Gay, 1980).

Based on the north-south orientation of the Aberjona River bedrock valley and the overburden materials that fill the valley, groundwater would be expected to travel through the valley in a southerly direction. Groundwater flow in the center of the Aberjona River bedrock valley is parallel to the axis of the valley (Myette et al., 1987).

Regional Groundwater Discharge and Recharge Areas

Surface water bodies and their associated wetlands within the watershed are generally assumed to represent groundwater discharge areas during base flow conditions. The highly transmissive stratified drift materials support the tendency for groundwater to discharge into the Aberjona River. As groundwater in the vicinity of the river flows towards it, it converges upward and discharges into the river. Groundwater discharging to the Aberjona River appears to flow through the adjacent wetland areas and through an underlying leaky streambed. Studies of flow duration on the Aberjona River observed that stream flow was sustained by groundwater discharge (Delaney and Gay, 1980). Groundwater flow toward the river can be temporarily reversed when the river stage rapidly increases during rainfall events (Solo-Gabriele, 1995). Another means of groundwater discharge is evapotranspiration, which is greatest from April to October in northeastern Massachusetts (Flanagan et al., 1999). Groundwater discharges are also attributed to withdrawals from pumping wells (see Section 3.2.2.3).

The major source of recharge to the overburden aquifer is precipitation. Precipitation enters the basin and either directly infiltrates into the overburden aquifer or runs over the land surface and infiltrates into the overburden aquifer in another area. The recharge areas of the basin can be inferred based on the characteristics of the surficial deposits and the slope of the land surface. These considerations limit the primary areas of recharge to the more permeable sands and gravels that occupy the lower, gently sloping areas of the basin. The hills that define the basin boundary are typically blanketed by glacial till deposits, which generally have a much lower hydraulic conductivity than the sands and gravels that occupy the valley floor. Additionally, the steeper topography near the basin rim will result in a greater volume of runoff during precipitation events than in the more gently sloping valley floor.

Some recharge will occur in areas of less permeable till and bedrock formations: However, it is assumed that the volume of this recharge is small in relation to the recharge of the overburden deposits in the floor of the valley. The average amount of recharge from precipitation to stratified drift aquifers in eastern Massachusetts is estimated to be 20 to 24 inches per year, approximately half of the total annual precipitation (Flanagan, et al., 1999). Surface water bodies and associated wetlands can also be groundwater recharge areas, particularly during "high water" periods, such as spring flood conditions. However, this seasonal event is likely to be of a short duration and the volume of recharge limited.

3.2.2 Study Area Geology

This section describes bedrock geology, overburden geology, and hydrogeology based on geologic investigations completed in the Northern Study Area. Groundwater was identified as a media of concern for the MSGRP and GSIP investigations, but was not a media of concern for the Aberjona River Study which focused on surface water, sediments and floodplain soils. Since geologic investigations were not conducted in the Southern Study Area along the Aberjona River and its floodplain as part of the MSGRP RI, the geology of the Southern Study Area is represented by the regional geology discussion (Section 3.2.1). The geologic information presented in this section is based primarily on the ISRT and GSIP investigations summarized in the following table. No subsurface geologic investigations were included in the scope of the MSGRP investigations. Information on the geology of the Wells G&H area is available from studies conducted for the other Wells G&H operable units, e.g. Geotrans, 1994; RETEC, 1994; and NUS, 1986.

Consultant	Investigation/Data Source	Year Investigation Conducted
Roux Associates	Phase I Evaluation of Waste Deposits and Subsurface Conditions	1982 – 1983
Roux Associates	Ground-water/Surface Water Investigation Plan, Phase 1 Remedial Investigation Report	1990
Roux Associates	Ground-water/Surface Water Investigation Plan, Phase 2 Remedial Investigation Report	1992
Roux Associates	GSIP Final Scope of Work Groundwater and Soil Investigation	2000 – 2001
Golder	Pre-Design Investigation Task GW-1, Plume Delineation Interim Final Report	1990
Golder	Pre-Design Investigation Task GW-2, Hydrogeologic Characterization for the Extraction/Recharge System Interim Final Report	1990
Golder	Pre-Design Investigation Slug Test Report	1990
Golder	Aquifer Pumping Test	1991

3.2.2.1 Study Area Bedrock Geology

The dominant bedrock types observed in the study area include gabbro-diorite and granodiorite. Boring logs from GSIP investigations in the Northern Study Area show the bedrock as a fine-grained, gray-green gabbro, a hornblende diorite with low quartz and trace pyrite, and a gray-green granodiorite. Bedrock fractures filled with sand and calcite were observed. During the MSGRP Hydrogeologic Investigation bedrock was drilled at only one location, and was observed as a dark green gabbro with horizontal fractures at a 60° angle. The study area bedrock geology is consistent with the regional bedrock geology.

The study area bedrock topography is consistent with the regional bedrock topography. There is one major bedrock valley, with minor bedrock valleys which join the major valley. The bedrock topography is shown in two graphical forms in Figure 3-2: bedrock elevation contours (left side of figure); and a three-dimensional view (right side of figure). The left portion of Figure 3-2 illustrates the bedrock topography by showing elevation contours developed using bedrock borings installed during several investigations. The boring logs used to construct these bedrock

elevation contours are included in the reports of the ISRT and GSIP investigations listed in the table above.

Bedrock elevations were observed to range from 116 feet (OW-2) in the Northern Study Area to -74.1 feet (S-76) just south of I-95 and Olympia Avenue. Bedrock elevations tend to decrease from north to south. The lowest elevations occur in the more central portion of the study area (e.g. borings ATB-15, OW-20, F-1D, and OW-27B), indicating a major bedrock valley feature within the central portion of the study area. Figure 3-2 also shows two minor bedrock valleys that both join the major central bedrock valley: one is in the northeast portion of the study area, in the area of the North Branch of the Aberjona River, and extends to the southwest; a second is in the area of North and South Ponds and extends south.

The right side of Figure 3-2 includes a three-dimensional image showing the bedrock elevations. The lowest elevation (dark blue) corresponds to the -40 foot bedrock surface contour; the major central bedrock valley is evident by the blue and dark green shading. The two minor bedrock valleys can also be seen, corresponding to the contour lines shown on the left side of the figure. A third, smaller bedrock valley can also be seen in the area of the South Branch of the Aberjona River.

3.2.2.2 Study Area Overburden Geology

The overburden geology of the study area is consistent with the regional overburden geology, with glacial deposits of stratified drift and till deposits overlain by recent peat, floodplain, and artificial fill deposits.

Geologic cross sections adapted from the GSIP Phase 1 investigation (Roux, 1991) are shown in Figures 3-3 and 3-4. The cross sections display the stratigraphy of the overburden deposits throughout the Northern Study Area. The five cross sections shown in the two figures were constructed using information from borings installed during the GSIP Phase 1 investigation and the pre-design investigations in 1990. The boring logs used to develop the cross sections are included in Appendix 3-B. The four cross sections shown on Figure 3-3 are oriented from west to east, intersecting the north to south cross section (Figure 3-4) at various locations. The Figure 3-3 cross sections show overburden materials of sand and gravel with trace silt that are thickest in the center of cross sections C-C' and D-D', filling the bedrock valley. The Figure 3-4

cross section (E-E') shows that overburden deposits are thin in the north and increase in thickness to the south corresponding to the bedrock elevations which decrease from north to south. The discussion of the overburden materials below groups the major units according to similar hydrogeologic properties. These major units include till, stratified drift (sand and gravel with intermittent layers of silt), and post-glacial surficial deposits (artificial fill, peat, and stream and swamp deposits).

Till Deposits

Till deposits throughout the Northern Study Area are composed of a poorly sorted to unsorted mixture of clay, silt, sand, and gravel. As shown in the cross sections (Figures 3-3 and 3-4), this deposit is discontinuous throughout the study area. Till deposits are located along the bedrock surface, primarily at high bedrock elevations, and are often not present at the bedrock surface within the bedrock valley, as shown on cross section E-E' (Figure 3-4). Till deposits vary in thickness in different areas. Cross section E-E' (Figure 3-4) shows a till layer ranging from 4 to 10 feet thick between ATB-12 and OW-16. Another till layer, of a similar thickness, is present between OW-18 and OW17 as shown on cross section B-B' (Figure 3-3).

Stratified Drift

Stratified drift deposits consist of graded sands with gravel and silt, and intermittent lenses of cobbles and boulders. The stratified drift deposits were deposited by melt waters from retreating glaciers. The deposits can be more than 100 feet thick in the center of the valley and thin to absent along the valley walls and areas where bedrock is close to the surface. The overburden aquifer is found in these deposits.

The stratified drift deposits, shown as sand on Figure 3-4, range in thickness from 6 feet (ATB-2) to 108 feet (ATB-15, which is located within central portion of the buried bedrock valley along the main bedrock valley axis). The GSIP investigation borings show that the stratified drift deposit is thin (e.g. less than 10 feet thick) in the northeast portion of the buried valley along the east bedrock valley wall. The stratified drift deposits (shown as sand) are 110 feet thick at OW-7B, located in the southwest portion of the buried bedrock valley (Figure 3-3, cross section D-D'). The boring log details for OW-27B show 69 feet of fine to medium sand and 31 feet of gray silt.

Post-Glacial Surficial Deposits

Post-glacial surficial deposits of artificial fill, topsoil, peat, and stream and swamp deposits overlie the glacial deposits at various locations throughout the Northern Study Area. Stream deposits have been observed in areas adjacent to the Aberjona River. Discontinuous peat deposits have been observed at the surface of marshy areas and other low-lying areas along the river. A peat layer was also observed underlying surficial sand deposits in the area of the former Mishawum Lake (shown in grey on Figure 2-3A). Soil cores collected from 0 to 4 feet within the HBHA show organic matter with some silt and peat in the top 2 feet, with medium to fine sands at 2 to 4 feet.

Soil samples collected from the former Mishawum Lake bed (Figure 2-3A) were used to describe the surficial deposits in the area. Peat deposits are generally composed of partially decomposed organic matter, such as roots or leaves, and often include intermittent layers of sand. The overlying sand deposits range in thickness from 1 (SO-13) to 24 feet (SO-12). The peat layer is relatively thin, ranging from 3 inches to 1 foot thick, and was found at depths of 3 feet (SO-08) to 23 feet (SO-17) bgs. As shown in Figure 3-3, peat and organic silt deposits are intermittent. A peat deposit, approximately 10 feet thick, was observed at boring OW-23 (B-B'). Organic silt deposits were observed at ATB-10 and ATB-20 (D-D') at approximately 18 feet and 2 feet thick, respectively. Peat deposits ranging in thickness from 4 to 6 feet were observed in the Wells G&H wetlands, interbedded with silt and sand (NUS, 1986; TRC, 2005).

Artificial fill has been used to fill in low lying areas in some portions of the Northern Study Area. The artificial fill deposits vary in thickness and are generally a sandy material (Roux, 1983). As shown by the cross sections (Figures 3-3 and 3-4), artificial fill has been identified at many boring locations overlying the sand layer, ranging in thickness from 2 to 15 feet. The fill deposits were described as consisting of manufactured or construction debris and waste sludge mixed with natural materials such as silty sand, gravel, or topsoil (Roux, 1983; Roux, 1991).

3.2.2.3 Study Area Hydrogeology

This section presents a discussion of the study area hydrogeology, including groundwater flow in the bedrock aquifer, groundwater flow in the overburden aquifer, overburden aquifer hydrogeologic characteristics, and groundwater classification and use. The discussion focuses

on the Northern Study Area and is based on hydrogeologic investigations conducted during the GSIP and MSGRP investigations. Hydrogeologic data is limited for the Southern Study Area because hydrogeologic investigations were not conducted in the area as part of the MSGRP RI. While not included in this RI, information on the hydrogeology of the Wells G&H area is available from studies conducted for the other Wells G&H operable units, e.g. Geotrans, 1994; RETEC, 1994; NUS, 1986; TRC, 2005.

Bedrock Aquifer

Monitoring wells were installed in the bedrock aquifer during the GSIP investigations; none were installed during the MSGRP investigations. Information from bedrock wells installed for an aquifer pump test was used to determine the interaction between the bedrock and the unconsolidated deposits. Based on the results of these tests, bedrock did not yield significant amounts of water (Golder, 1991c). Some interaction between the overburden and bedrock aquifers was observed during the aquifer pumping test conducted during the GSIP Phase 1 investigation (Golder, 1991c). This interaction was indicated by the fluctuation of groundwater levels within bedrock wells during the pump test. The transmissivity values calculated for the bedrock were low and the amount of water from the bedrock during the pump test was minimal in comparison to the contribution of groundwater from the overburden (Golder, 1991c).

The groundwater flow interaction between the unconsolidated deposits and bedrock was also evaluated during the GSIP Phase 2 investigation. Three bedrock wells were installed. OW-51B and OW-53B, installed 50 feet into bedrock, were dry upon completion. Groundwater was monitored in the wells for several weeks; the recharge of groundwater into the wells was estimated as 0.2 to 2 feet per day. Groundwater recovered during installation of the third bedrock well, OW-55. This well exhibited vertical gradients ranging from 0.0084 ft/ft to 0.334ft/ft based on water level measurements and a comparison to OW-54C, an observation well screened in the basal unconsolidated deposits (Roux, 1992). These investigations indicated that bedrock generally exhibits low permeabilities and very small gradients in the bedrock aquifer.

Overburden Aquifer

Stratigraphy - The overburden aquifer consists of stratified drift deposits of sand and gravel as described in Section 3.2.2.2. The aquifer thickness parallels the thickness of the sand and gravel deposits (see Figures 3-3 and 3-4) and increases in thickness to the south. The aquifer is thinnest in the northern, eastern, and western portions of the study area, consistent with the orientation of the bedrock valley.

Groundwater Flow - Data collected during the 2002 MSGRP Hydrogeologic Investigation were used to evaluate groundwater flow direction and gradients in the overburden aquifer. Generally groundwater flows in a southerly direction, mimicking the topography of the buried bedrock valley and tends to flow toward the Aberjona River. Synoptic water level rounds (completed after 2 consecutive days without precipitation) were conducted on April 18, 2002, July 30, 2002, and October 28, 2002, at 48 well locations and four surface water stations. Figures 3-5 to 3-7 show water table, or shallow groundwater, elevation contours developed for each of the three synoptic water level rounds based on the recorded groundwater and surface water levels (see Appendix 3A-1). The groundwater elevations ranged from 49.87 feet (E-3, E-4; 7/30/02) to 74.7 feet (A-9; 4/18/02) over the three water level rounds.

The water table elevation contours shown in Figures 3-5 to 3-7 indicate similar groundwater flow patterns and trends and no significant seasonal fluctuations. The contours indicate that groundwater tends to flow in a southerly direction, with the highest elevations (A-9) in the northern portion of the study area and the lowest elevations (MW-9) in the southeast portion of the study area. As shown on the three water table contour figures, groundwater flows from the west to the southeast and from the east to the southwest. The shape of the contour lines indicates one central valley which is in alignment with the bedrock valley (Figure 3-2). The contour lines also indicate that groundwater flows into the HBHA and south of the HBHA along the Aberjona River. These 2002 groundwater contour maps are consistent with previous investigations (Roux, 1991) and indicate shallow groundwater flow in the direction of the Aberjona River and associated tributaries, while groundwater flow at greater depths is parallel to the main buried valley.

Horizontal Gradients – The average horizontal gradient calculated for each water level round was: 0.00594 ft/ft on April 18, 2002; 0.00547 ft/ft on July 30, 2002; and 0.00566 ft/ft on

October 28, 2002 (see Appendix 3A-2 for elevations and calculated gradients). The 2002 horizontal gradients are generally within the range of the horizontal gradients calculated during the pre-design investigations, 0.002 to 0.009 ft/ft (Golder, 1991), and the GSIP Phase 1 investigations, 0.004 ft/ft to 0.008 ft/ft (Roux, 1991).

Vertical Gradients – Vertical gradients could not be accurately calculated from the data collected during the MSGRP investigation due to the use of direct push technology drilling and the discrete groundwater sampling procedure employed during the investigation. As described in Section 2.2.2.4, discrete groundwater samples were collected from the overburden aquifer from the shallow, intermediate, and deep intervals of the aquifer from each borehole. The water levels were measured at the deeper aquifer interval soon after purging the aquifer at a shallower depth. This likely did not allow sufficient time for the water level to fully recover. As a result, the calculated vertical gradients are inconsistent and variable (see Appendix 3A-3).

During the GSIP Phase 1 investigation, seasonal water levels were measured from eight monitoring well clusters screened in the shallow and deep portions of the overburden aquifer. This investigation found that the calculated vertical gradients did not indicate a “significant” flow in the unconsolidated aquifer, either upward or downward (Roux, 1991). Nine sets of measurements made during the period of June 1990 to May 1991 were used to calculate the vertical gradients between the shallow and deep portions of the overburden aquifer. The calculated downward gradients ranged from 0.0003 ft/ft to 0.040 ft/ft and the upward gradients from 0.0003 ft/ft to 0.026 ft/ft (Roux, 1991). The 0.040 ft/ft downward gradient measured at OW-7, located adjacent to Mishawum Road, was not considered representative of the unconsolidated deposits in the balance of the study area since the well cluster was installed in two different lithologic zones (Roux, 1991). Measurements from monitoring well clusters were also used to calculate vertical gradients between the overburden aquifer and the upper bedrock during the pre-design investigation plume delineation study. The vertical gradients ranged from 0.006 ft/ft downward to 0.034 ft/ft upward (Golder Associates, 1990). Additional data collected during the GSIP Phase 2 investigation indicated upward and downward vertical gradients as well as horizontal gradients in the area of the north end of the HBHA during the winter of 1992 (Roux, 1992) (refer to Appendix 3A-4).

Hydrogeologic Characteristics - The hydrogeologic characteristics of the overburden aquifer, including hydraulic conductivity and transmissivity, are important factors for evaluating the

quantity of groundwater flowing through the overburden aquifer system, the rate of flow, and the direction of groundwater flow. Data collected during GSIP investigations, including pump tests and slug tests, were used to describe the overburden aquifer characteristics since subsurface investigations were not conducted during the MSGRP Hydrogeologic Investigation.

Two pump tests and two slug tests were conducted as part of the GSIP pre-design investigations, in December 1990 and December 1991. The average horizontal hydraulic conductivity values determined from the pump tests ranged from 40.28 gpd/ft² to 4,240 gpd/ft², and the average vertical hydraulic conductivity values ranged from 0.04876 gpd/ft² to 6,572 gpd/ft² (Golder, 1990, 1991c). The average horizontal hydraulic conductivity values determined from the slug tests ranged from 15.2 gpd/ft² to 2,713.6 gpd/ft² (Golder, 1990, 1991b). The following table is a summary of the studies conducted and the range of average hydraulic conductivities (K) determined during each study.

Consultant	Investigation	Test Type	Range of K Values
Golder Associates	GSIP, Pre-design Investigation, Task GW-2 – Hydrogeologic Characterization For The Extraction/ Recharge System, December 1990	Pump Test	280 gpd/ft ² – 2600 gpd/ft ²
Golder Associates	GSIP, Pre-design Investigation, Task GW-2 – Hydrogeologic Characterization For The Extraction/ Recharge System, December 1990	Slug Test	Bouwer and Rice Analysis: Falling Head Test 15.2 gpd/ft ² – 888 gpd/ft ² Rising Head Test 10.4 gpd/ft ² – 1250 gpd/ft ² Hvorslev Analysis: Falling Head Test 15.4 gpd/ft ² – 1090 gpd/ft ² Rising Head Test 22.7 gpd/ft ² – 1250 gpd/ft ²
Golder Associates	GSIP, Pre-Design Investigation Slug Test Report, January 1991	Slug Test	16.13 gpd/ft ² – 2,713.6 gpd/ft ²

Consultant	Investigation	Test Type	Range of K Values
Golder Associates	GSIP, Aquifer Pumping Test, December 1991	Pump Test	<p>Neuman Analysis</p> <p>Approach 1: Base of the aquifer at the top of bedrock/till Horizontal K = 40.28 gpd/ft² – 4,240 gpd/ft² Vertical K = 0.20352 gpd/ft² – 2.968 gpd/ft²</p> <p>Approach 2: Aquifer includes upper 15 feet of till and bedrock Horizontal K = 209.88 gpd/ft² – 2,544 gpd/ft² Vertical K = 0.04876 gpd/ft² – 6,572 gpd/ft²</p>

Typical hydraulic conductivity values for well-sorted sand units (similar to the stratified drift deposits), ranged from 21.2 gpd/ft² to 21,200 gpd/ft² (Fetter, 1994). The hydraulic conductivities measured in the study area are within the same order of magnitude.

Groundwater - Surface Water Interaction

Hydrogeologic investigations have indicated a groundwater and surface water interaction throughout the study area. Generally, the shallow groundwater of the overburden aquifer flows into surface water bodies and wetland areas.

During the GSIP Phase 1 investigation, groundwater and surface water levels were measured from piezometers located along the Aberjona River. The water level measurements indicate that the Aberjona River is a gaining stream receiving groundwater discharge. However, the reverse was observed during rainfall events when the river recharges groundwater (Roux, 1991). A seepage study conducted in the HBHA during the GSIP Phase 2 investigation determined that the rate of groundwater discharged to the surface water of the HBHA Pond ranged from 6.9×10^{-4} ft³/ft²/day to 7.3×10^{-3} ft³/ft²/day, with average groundwater discharge rates for the base of the pond of 720 ft³/ft²/day (Roux, 1992).

As part of the MSGRP Hydrogeological Investigation, piezometers were installed to evaluate the interaction between groundwater and surface water. The piezometers were located within the stream bed at each of the 10 TtNUS surface water station locations (see Section 2.2.2.2), with

the exception of Stations 4 and 9. A comparison of groundwater and surface water elevations at each of the stations where piezometers were located indicate that groundwater generally discharges into surface water during base flow conditions. Exceptions to this discharge pattern were noted at Station 1, where groundwater was consistently recharged by surface water, and Station 8, where groundwater was recharged by surface water seasonally. During storm events, water elevations (both groundwater and surface water elevations) were higher, and surface water recharged to groundwater, except at Stations 3 and 7 where groundwater continued to discharge into surface water. Data graphs included in Appendix 3A-5 display the relationship between groundwater and surface water levels.

3.2.2.4 Groundwater Classification and Use

The MADEP Bureau of Waste Site Cleanup has developed a groundwater classification system for use in risk characterization at disposal sites. The three classes of groundwater (GW-1, GW-2 and GW-3) and contaminant criteria applying to each are established in the MCP. Groundwater is classified as GW-1 if it is located within a current or potential drinking water source area. The GW-2 classification applies to areas where there is the potential for migration of vapors from the groundwater to the air inside occupied structures. Specifically, the GW-2 classification applies to groundwater located within a 30-foot radius of an existing occupied building or structure, where the average annual depth to groundwater in the area is 15 feet or less. The GW-3 classification applies to groundwater that may impact surface water. All groundwater is considered a potential source of discharge to surface water and therefore is, at a minimum, categorized as GW-3 (310 CMR 40.0932).

The groundwater classifications for the MSGRP RI Study Area were identified by MADEP and documented in their "Groundwater Use and Value Determinations" for the Industri-plex and Wells G&H Sites (MADEP 1997 and 2003), at the request of EPA and were used by EPA in developing and evaluating site-specific risk assessment scenarios.

Overall, the purpose of the Use and Value Determination is to identify whether the aquifer at the Site should be considered a "high," "medium," or "low" use and value aquifer. The description of the on-site groundwater was determined by the MADEP, based on the balancing of eight factors:

- quantity or potential yield of the aquifer
- quality of the water within the aquifer
- if the aquifer is a current public drinking water supply
- if the aquifer is a current private drinking water supply
- likelihood and identification of future drinking water use
- other current or reasonable expected groundwater uses
- ecological value
- public opinion

Upon agreement by EPA, this determination will be considered when evaluating potential risks, setting the remedial objectives, and selecting the remedial action.

Industri-plex Site

The MADEP “Groundwater Use and Value Determination” for the Industri-plex Site (MADEP, 1997) concluded that the aquifer from the Industri-plex Site south to I-95 (the Northern Study Area) was of low use and value. This determination was reaffirmed in a clarification issued by MADEP in March 2004 (Mayor, 2004). The determination and the clarification are included in Appendix 3C-1. The use and value determination report in Appendix 3C-1 includes a figure that shows the aquifer classification and groundwater resources in the area of the Industri-plex Site.

The MADEP concluded that, with the exception of two small areas that may be classified as GW-1 (Phillip’s Pond and south of the easternmost extension of the NStar [formerly BECO] ROW), the Industri-plex area aquifer was classified as a Non-Potential Drinking Water Source Area (NPDWSA) because of its concentrated industrial development. MADEP concluded that a low use and value determination was appropriate for the entire area despite the presence of the two potential GW-1 areas because commercial development and other factors make it unlikely that public drinking water facilities would be developed in the areas (Mayor, 2004).

Due to its designation as a low use and value NPDWSA, the MADEP concluded that for the purposes of the risk assessment, the groundwater in the Industri-plex area is classified as GW-2 and GW-3. The GW-2 classification applies to any areas where there are occupied structures and the average depth to groundwater is 15 feet or less. The GW-3 classification applies to the entire study area.

As indicated in the section below, the edge of the Interim Wellhead Protection Area (IWPA) for Woburn municipal wells G & H is at Interstate 95, the southern boundary of the Industriplex/Northern Study Area. Although the wells are inactive, they are still considered a public water supply and the MCP requires that groundwater flowing into an IWPA must meet drinking water standards (GW-1 criteria). Therefore, although the Northern Study Area groundwater is classified as GW-2 and GW-3, the groundwater at its southern border must meet GW-1 standards before entering the IWPA.

Wells G&H Site

The MADEP “Groundwater Use and Value Determination” for the Wells G&H Superfund Site (MADEP, 2004) concluded the aquifer in the area of the Wells G&H Site is of medium use and value. The use and value determination report is included in Appendix 3C-2; the report includes a figure that shows the aquifer classification and groundwater resources for the Wells G&H Site area.

Nearly the entire Wells G&H Site, including the 38-acre wetlands lies within the IWPA of municipal wells G&H. An IWPA is defined as the area within a 0.5-mile radius of a public water supply that does not have a delineated Zone II. (Zone II, as defined in the 2001 MADEP Groundwater Source Approval Regulations, is the area of an aquifer which contributes water to a well under the most severe pumping and recharge conditions that can be realistically anticipated.) Although the wells are inactive, they are still considered a public water supply.

Because the Wells G&H aquifer is within the IWPA and because it is a medium and high yield aquifer, the site area aquifer is classified under the MCP as a GW-1 area. The 0.5-mile radius of the IWPA takes precedence over areas excluded as non-drinking water source areas under the MCP; therefore, regardless of other designations the whole area within the IWPA is considered a current drinking water source area (MADEP, 2004). Due to the development in the area, the GW-2 classification also potentially applies to most of the aquifer (MADEP, 2004). Lastly, at a minimum, all groundwater is considered as GW-3. The aquifer discharges into the Aberjona River and wetlands and must meet all applicable standards.

MADEP concluded that a medium use and value determination was appropriate for the Wells G&H area aquifer because of its significant current and future ecological value to the Aberjona

River and associated wetlands and its potential human value as a drinking water supply in the future.

3.2.2.5 Groundwater Users

The City of Woburn has historically withdrawn groundwater from the Horn Pond and Aberjona River aquifers for its municipal water supply. Production wells installed near Horn Pond have been used since 1931. Production wells G&H were installed in 1964 and 1967, respectively, and used until 1979, when they were closed due to VOC contamination. Since these two wells were shut down in 1979, Woburn has received approximately 60 percent of its water supply from the Horn Pond wells and the remainder from the Massachusetts Water Resource Authority (MWRA). The City of Woburn has the only registered potential groundwater supply source in the study area, and is registered for a total water withdrawal of up to 4.2 mgd for use city-wide (Woburn Water Department, 2003). The average water withdrawal from the Horn Pond wells is 3.7 mgd (Woburn Water Department, 2003). Table 3-1 shows historical and current groundwater users in Woburn.

The Town of Winchester does not use groundwater for drinking water purposes. Many private residential wells have been installed recently for irrigation purposes. Table 3-1 shows historical and current groundwater users in Winchester.

Groundwater wells used for irrigation, industrial processes, and monitoring exist throughout the study area. Generally, it is assumed that these wells do not consistently withdraw a significant amount of groundwater, and therefore are not expected to have an influence on area-wide groundwater flow direction. However, the Atlantic Gelatin (Kraft Foods) industrial production wells have historically withdrawn significant amounts of groundwater from the study area. Atlantic Gelatin has installed and operated a total of seven production wells; three are currently in operation. Presently, the total permitted withdrawal rate is 1 mgd. Approximately 800,000 gallons per day are withdrawn from Atlantic Gelatin wells located in Winchester. The balance of approximately 200,000 gallons per day is withdrawn from Well No. 7, located in Woburn, near Whittemore Pond. According to Atlantic Gelatin personnel, withdrawal rates have remained fairly consistent since the 1980s: The exact historical withdrawal rates are not known, but were likely somewhat higher (Lowery, 2002). Other users of groundwater for industrial process water have included the John J. Riley Leather Company, Johnson Brother's Roses, Independent

Tallow, and Stauffer Chemical Company in Woburn; also J.O. Whitten and Parkview Apartments in Winchester (CDM, 1967). One of the two Riley tannery production wells was reported to yield 750 gpm and the Stauffer Chemical Company well(s) reportedly yielded 1.0 mgd (CDM, 1967).

3.3 Surface Water Hydrology

The major surface water bodies in the MSGRP RI Study Area are the Aberjona River and Mystic Lakes. The Aberjona River flows through the central portion of the study area from north to south, where it discharges to the Upper Mystic Lake. Other surface water bodies located throughout the study area discharge water into or receive water from the Aberjona River. The Aberjona River and associated water bodies are shown on Figure 3-8. These surface water bodies are recharged by both precipitation and groundwater. The average annual precipitation for the Aberjona River watershed is 45.3 inches according to the weather station in Reading, Massachusetts. Precipitation reaches the Aberjona River by man-made routes and natural surface runoff. During periods without precipitation, water is supplied to the river primarily by groundwater (Solo-Gabriele, 1995). Surface water hydrology, drainage patterns, and water quality classification are discussed below.

3.3.1 Aberjona River

The Aberjona River is the primary river system in the study area. It has a drainage area of approximately 25 square miles (Solo-Gabriele, 1995). The river originates in a low-lying wetland area at an elevation of 120 feet, in Reading, Massachusetts. The river flows for approximately 9 miles in a southward direction and discharges into the Mystic Lakes at an elevation of approximately 3 feet. The average discharge is reported to be 29.5 cubic feet per second (cfs) at the USGS station located approximately 0.5 mile upstream of Upper Mystic Lake in Winchester (USGS, 1999).

The general slope of the Aberjona River is 0.002 ft/ft. The width and depth of the river increases in the downstream (southerly) direction. The main tributary to the Aberjona River is Horn Pond Brook, which drains approximately 40 percent of the watershed area (Solo-Gabriele, 1995). Other tributaries to the Aberjona River include Halls Brook, Snyder Creek, Sweetwater Brook, and Whittemore Pond Brook.

The amount of runoff to the river has increased significantly over the past 30 to 40 years due to industrial and commercial development in the watershed. The inflow volume varies as a result of storm events. The river is directed through many man-made features such as bridge openings, culverts, dams, and siphons. The Aberjona River has frequently overflowed and flooded low-lying areas adjacent to the river in Winchester; recent floods occurred in October 1996 and June 1998 (CDM, 1999). A 1999 study conducted for the Town of Winchester included recommendations to modify the river and manmade structures along the course of the river to improve flow and reduce the flooding conditions. The Town of Winchester is currently evaluating regulatory and budgetary issues associated with deepening and widening the river at specific locations.

The City of Woburn has also suffered from the effects of flooding along the river. According to the Woburn Daily Times Chronicle and the Woburn Advocate newspapers, flooding in the City occurred in 1996, 1998, 1999, and 2001. The City is also evaluating engineering solutions to reduce flooding in low-lying areas (TtNUS, 2003).

3.3.2 Drainage Patterns

Surface water in the study area generally flows in a southward direction, from topographic highs to topographic low areas. Most surface water bodies in the watershed flow toward and discharge into the Aberjona River, which flows south and discharges into the Upper Mystic Lake. Changes in drainage patterns for the Aberjona River and related surface water bodies in the watershed have occurred over the past 40 years. Aerial photographs taken in 1938 show peat bogs and swampy terrain along the length of the Aberjona River valley (EPA, 2002). By 1980, the aerial photographs show a 50 percent reduction of peat bogs and swamps due to urban and industrial growth (EPA, 2002).

Several surface water bodies in the Northern Study Area have undergone significant changes as a result of property development activities around the Industri-plex Site between 1970 and 1983. The most significantly impacted surface water bodies are the Aberjona River including the North and South Ponds, the Atlantic Avenue Drainway, and the former Mishawum Lake (see Figure 3-8). In 1974, the North and South Ponds were partially filled. In 1979, EPA obtained a court order to stop development activities on the site. The Industri-plex Site was listed on the National Priorities List (NPL) as a Superfund site in 1983. Based on a review of historical USGS

topographical survey maps, the surface drainage paths surrounding the Industri-plex Site remained largely unchanged from 1944 through 1965. Prior to 1965, two branches of the Aberjona River (North and South Branch) flowed from North Reading, joined at a point south of what is currently the Industri-plex Site, and discharged to Mishawum Lake. The Aberjona River then resumed flow at the southern end of Mishawum Lake near Mishawum Road.

In the early 1970s, Mishawum Lake was drained, the Aberjona River was rerouted, and the HBHA was constructed as a flood control structure and to receive drainage from the Industri-plex Site. These changes can be seen on the historical photographs in Figure 1-3. In the mid 1970's construction of Commerce Way resulted in the Aberjona River being directed into a continuous open channel flowing between the two lanes of Commerce Way. The Aberjona River now joins the outflow from the southern end of the HBHA at Mishawum Road and continues to flow south under I-95. The Atlantic Avenue Drainway, constructed in 1995, receives flow from the surrounding developed areas and South Pond through the Created Wetland and discharges to the HBHA. Another drainway was constructed to allow flow from the North Branch of the Aberjona River into Phillips Pond; however a hydraulic connection was not successfully established and the drainway now empties a wetland to the north of Phillips Pond. The changes described above as well as the current surface water features are illustrated on Figure 3-8. The physical changes described above are summarized in greater detail in an earlier report (HNUS, 1997).

Changes to the Aberjona River have also been made on segments of the river in the Southern Study Area from Salem Street south to the southern extent of the Mystic Lakes. The course of the river prior to these changes is indicated on Figure 3-8; the location of each of the four course changes described below is highlighted and described in the Legend. The four changes include:

- A diversion in the late 1940s upstream of the present day Manchester Field to increase the size of the recreational area. The river presently flows east of its original location, on the east side of Boston and Maine Railroad tracks. (Figure 3-8, Legend item 7)
- A change in course in the early 1950s due to filling of land and construction of buildings where the tributary from Horn Pond connects with the Aberjona River. (Figure 3-8, Legend item 6)

- A diversion in the mid 1960s through a large underground culvert located at Winchester High School. The area was filled in to increase the size of the recreational park, and included filling a portion of Judkins Pond to construct the present day athletic field at Winchester High School. (Figure 3-8, Legend item 5)
- A diversion in the 1970s due to development on the north side of Montvale Avenue including construction of buildings and parking lot areas. (Figure 3-8, Legend item 4)

3.3.3 Surface Water Classification and Use

The Aberjona River is classified as a Class B water by MADEP. Class B waters are defined in 314CMR4.05(3)(b) as: “a habitat for fish, other aquatic life, and wildlife, and for primary and secondary contact recreation.” Class B waters are suitable as a source of public water supply with appropriate treatment. They are considered suitable for irrigation and other agricultural uses and for compatible industrial cooling and process uses, and must have consistently good aesthetic value. The Mystic Lakes are the major surface water bodies in the study area that are used for recreational purposes. Currently, there are no known surface water withdrawals from the Aberjona River or NPDES-permitted industrial effluent discharges into the Aberjona River.

3.4 Wetlands and Floodplains

The major wetlands located in the MSGRP RI Study Area include the Halls Brook Holding Area wetland, the Wells G&H wetland, and the Cranberry Bog Conservation Area wetland. Less significant wetland areas are scattered throughout the study area and include the Created Wetlands, wetlands adjacent to I-93, and wetlands surrounding the Aberjona River and associated surface water bodies. The major wetland areas and floodplain of the Aberjona River are discussed below.

3.4.1 Halls Brook Holding Area

The HBHA is located in Woburn, Massachusetts, immediately south of the Industri-plex Site and approximately 0.6 miles north of Wells G & H (Figure 3-8). The HBHA is a man-made detention basin constructed to provide flood storage in the area. The HBHA occupies approximately 15.2 acres, consisting of a 4.6-acre pond and three minor ponds and wetlands. The northernmost pond is significantly larger than the others and is referred to as the HBHA Pond in this report. The other ponds are referred to in this report as HBHA Pond 1, HBHA Pond 2 and HBHA Pond 3, referenced from north to south, respectively.

The HBHA Pond is approximately 1100 feet long, 190 feet wide, and 14 feet deep, with an estimated volume of 39,000 cubic meters (Roux, 1992). The pond receives water from various sources including: Halls Brook, a significant surface water source discharging 2.79 cfs to the HBHA; the Atlantic Avenue Drainway, an open channel with minor flow; and groundwater discharge. The combined flow from these three sources is released from the HBHA Pond outlet at an approximate discharge rate of 3.27 cfs (LeMay, 1998). The water discharged from the HBHA Pond travels through the HBHA wetland area. The wetland area is approximately 3900-feet long and contains the three small ponds referred to above (LeMay, 1998). At the southern terminal point of the HBHA wetland, the Aberjona River merges with the outflow of HBHA wetlands at Mishawum Road and continues south under I-95.

3.4.2 Wells G&H Wetland

The Wells G&H wetland is an approximately 38-acre naturally-occurring wetland located just south of Olympia Avenue and extending south to Salem Street (Figure 3-8). It is bordered by the Boston and Maine railroad tracks to the west and Washington Street to the east. The Aberjona River generally flows through the central portion of the Wells G&H wetland. Development activities in the 1900s have encroached on the wetland areas.

3.4.3 Cranberry Bog Conservation Area

The Cranberry Bog Conservation Area (CBCA) was operated as a commercial cranberry bog from 1910 to 1939. The cranberry bog is located south of Salem Street and west of Washington Street, and continues south to Washington Street Circle (Figure 3-8). The CBCA occupies an

area of approximately 17 acres (CDM, 1999). The CBCA is presently a conservation area maintained by the Woburn Conservation Commission with financial assistance from the Massachusetts Department of Natural Resources. Residential areas abut the west and east borders of the CBCA, and the Aberjona River flows directly through the center of this area.

3.4.4 Aberjona River Floodplain

The Aberjona River floodplain lies adjacent to the Aberjona River and varies in width throughout Woburn and Winchester. The floodplain lies within the FEMA-designated 100-year flood zone. Much of the river's floodplain has been lost or impacted due to urbanization and channelization of the river. Examples of such areas are the HBHA, the Wells G&H wetlands, the Cranberry Bog, Davidson Park, Leonard Pool, and the area around Judkins Pond and the Winchester High School recreational fields.

3.5 Climate and Meteorology

The MSGRP RI Study Area is located in a humid, temperate New England climate, with seasonal weather patterns and temperature. The following resources were used for this discussion:

- Precipitation data recorded at the Reading - 100 Acre Pumping Station; located off Grove Street, at the end of Stout Avenue, in Reading, Massachusetts and approximately 1 mile from the Aberjona River Watershed.
- Precipitation and temperature data recorded at the Reading National Climatic Data Center (NCDC) located at 35 Arcadia Avenue in Reading, Massachusetts.
- Wind, temperature, and precipitation data recorded at the National Oceanic and Administration Association (NOAA) station located at Logan Airport, approximately 30 miles south of the study area.

3.5.1 Precipitation

According to historical precipitation records collected between 1899 and 2002 at the Reading weather stations, the average annual precipitation is 43.5 inches. The driest year occurred in 1965, with an average yearly rainfall of 27.1 inches; the wettest year occurred in 1983, with an average rainfall of 63.5 inches. Historically, the highest average rainfall occurs in November (4.10 inches), closely followed by March (4.06 inches). The lowest average rainfall occurs in July (3.31 inches) and August (3.33 inches). Monthly average rainfall recorded at the Reading NCDC for the period of record (1899 to 2002) and for the years when TtNUS conducted the MSGRP field investigations (2001 and 2002) are shown in the table below.

READING-NCDC MONTHLY RAINFALL AVERAGES (inches)			
Month	1899 – 2002 Averages	2001 Averages	2002 Averages
January	3.76	2.71	3.82
February	3.37	2.66	2.34
March	4.06	12.8	4.14
April	3.89	1.31	3.95
May	3.39	1.85	7.23
June	3.41	7.67	3.36
July	3.31	2.63	2.08
August	3.33	6.27	2.46
September	3.66	1.89	3.35
October	3.36	1.20	4.56
November	4.10	1.01	6.02
December	3.94	3.58	6.86

Hourly precipitation data from the Reading NCDC weather station is available from 1981 to the present day. According to the historical rainfall data collected at the Reading weather station, 2,230 storms of 0.02 inches of accumulation or greater have occurred between 1981 and 2002.

3.5.2 Temperature

According to National Weather Service (NWS) historical climate data for the period of record (1888 to 2000), average monthly temperatures for Boston, Massachusetts ranged from 28.6°F (January) to 73.5°F (July). Based on historical climatic data collected at the Reading weather

station for the period of record from January 1993 to August 2002, the mean temperatures ranged from 25°F to 73°F, with coldest months being January and February and the warmest months being July and August.

3.5.3 Wind

The average monthly wind speed ranges from 10.8 to 13.7 miles per hour for the region, according to NOAA historical records. The lowest averages occur in August and the highest averages occur in January and February. The prevailing wind direction is west – northwest.

4.0 NATURE AND EXTENT OF CONTAMINATION

This section summarizes the analytical results obtained during the investigations supporting this RI and described in Section 2.0, to characterize the nature and extent of contamination in the MSGRP RI Study Area. The analytical results are presented by media and type of analysis. In addition, this section includes an overview of potential contamination sources that may have impacted the study area.

4.1 Potential Contamination Sources

A number of investigations and reports concerning area-wide contamination have been used to support the MSGRP RI. The Preliminary MSGRP report, completed in 1997, covered the area north of I-95 including the Industri-plex Site. This area is referred to in this MSGRP RI as the Northern Study Area. The Preliminary MSGRP Supplemental Report – Southern Area addressed portions of the Aberjona River watershed from I-95 south to the Mystic Lakes, as well as the Wells G&H Site. This area is referred to in this RI as the Southern Study Area. The two preliminary MSGRP reports compile information obtained from MADEP file reviews, RI reports for the Industri-plex and Wells G&H Sites, and MIT research studies. These resources identified historical activities and recent industrial operations and activities as potential contamination sources that may contribute to surface water, sediment, or groundwater contamination at or adjacent to the MSGRP RI Study Area.

This discussion of potential contamination sources is organized into two parts: a discussion of historical activities and sources identified as the major potential contributors to contamination in the Northern Study Area; and sources identified as major potential contributors to contamination in the Southern Study Area.

4.1.1 Northern Study Area Sources

The Northern Study Area has been the site of extensive industrial activities since the early 1800s. These industries have included tanneries, leather finishing companies, chemical manufacturers, landfills, open burning dumps, metal fabricators, and piggeries, which have contaminated groundwater, surface water, and/or sediments within the Aberjona River Watershed. In addition, numerous sites within the watershed have contaminated groundwater

and soils due to leaking USTs. Key historical activities which may have contributed contamination in the Northern Study Area are briefly discussed in Section 4.1.1.1. The history of industrial activities at and contamination associated with the Industri-plex Site is discussed in Section 4.1.1.2. Potential sources of contamination from other sites evaluated in the Preliminary MSGRP Report and subsequently included in the MSGRP RI field investigations are discussed in Section 4.1.1.3. Table 4-1 provides general information about the potential sources, including dates of operation, type of industry, chemicals used and products produced, and potential contaminants. These potential sources are shown on Figure 4-1a.

4.1.1.1 Historical Activities in the Northern Study Area

The leather industry, which included leather tanneries, finishers, and rendering plants, was a significant industry in Woburn from 1875 to 1968 (Durant, et al., 1990). The New England Chemical/Stauffer Chemical glue factory operated on the Industri-plex Site between 1934 and 1969. Leather-related companies have been identified as a significant historical source of pollution in the Aberjona River and its tributaries due largely to the direct discharge of process wastes to surface waters in the area.

Prior to 1932, wastewater from leather-related companies in the area was typically discharged directly into the Aberjona River and its tributaries. After the completion of a Metropolitan District Commission sewer extension in 1932, much of the tannery waste from facilities in North Woburn was discharged to the sewer system; however, capacity limits and plugging of the sewer lines from high concentrations of solids in the tannery wastewaters resulted in periodic overflows. On-site settling lagoons were eventually used to pre-treat the tannery wastewater to remove solids prior to discharge into the sewers. These settling lagoons created a large volume of dense sludge that was periodically removed and disposed of in area landfills or buried on-site, as on the Industri-plex Site (HNUS, 1997; Durant, et al., 1990). Hazardous materials typically associated with the leather industry include chromium, copper, lead, and zinc.

Historical records show a number of open dumps operated in Woburn between the 1920s and 1960s and were used for disposal of municipal solid wastes, industrial wastes and open burning (Tarr, 1987). During the period from 1953 to 1965, the City of Woburn disposed of its solid waste at an open dump operated by Allstate Sand and Gravel. The dump was located north of Mishawum Road, southeast of New Boston Street, and west of the Boston & Maine Railroad

(Figure 4-1a) (Geotrans, 1987). Open burning occurred at the dump until May 1962 when the owners were ordered to cease burning by the Woburn Board of Health.

The Woburn Sanitary Landfill, located off Merrimac Street in North Woburn (Figure 4-1a), operated from 1966 until 1986. The landfill reportedly received various types of wastes including residential/commercial waste, raw sewage, burned waste, construction/demolition debris, and more than 20,000 cubic yards per year of "gelatin sludge" from General Foods (Atlantic Gelatin). It also received tens of thousands of cubic yards of refuse mined from an existing landfill (the Allstate Sand and Gravel Dump) that was being developed into the Woburn Industrial Park. An Administrative Consent Order was issued in 1996 to close the unlined landfill. Leachate from the landfill flowed to the New Boston Street Drainway, which discharges into Halls Brook. The results of groundwater monitoring conducted as part of the landfill closure activities indicated that the contaminants were typical of solid waste disposal landfill leachate and did not present an environmental or imminent health hazard (MADEP, 2002a).

4.1.1.2 Industri-plex Site

The primary sources of contamination at the Industri-plex Site were the former operations and disposal activities of Merrimac Chemical/Monsanto and New England Chemical/Stauffer (Figure 4-1a). Merrimac Chemical operated at the site from 1853 until 1931 and generated wastes from the production of sulfuric acid, lead arsenate pesticides, and organic chemicals (phenol, benzene, picric acid, toluene, and TNT). Wastes were deposited throughout the site and were used as fill in low/wet areas and to construct dikes to contain liquid wastes. Disposal occurred in a wide area of the property west of the current location of Commerce Way and also further west across the railroad tracks. The wastes contained arsenic, chromium, lead, zinc, and copper.

New England Chemical/Stauffer operated a glue factory at the site from 1935 until 1968. Liquid wastes were discharged into a settling lagoon before discharge to the city sewer. Solid wastes, including sludge from the lagoon, hides, and tankage (solids consisting of wood shavings, raw products and hide materials from cooking tanks), were primarily disposed of east and southeast of the glue factory. The glue production wastes were often buried on top of chemical manufacturing wastes. The glue wastes contained chromium and organic materials such as leather scraps, hair, and fleshings.

In the early 1970s development activities by the Mark Phillip Trust resulted in the movement of soil and some wastes from their original locations to various locations on the site. The excavations encountered buried chemical and glue manufacturing wastes, which were moved, and in some cases stockpiled in the northern portion of the site, creating the West and East Hide Piles. Wastes in other portions of the site which were not impacted by development activities remained undisturbed. Subsurface investigations completed in the early 1980s noted that approximately 92 of the 244 acres included in the investigation contained contamination (Stauffer, 1983). The Phase I Report (Stauffer, 1983) documented the following contaminant distribution and concentrations:

- Arsenic and lead were the most prevalent contaminants; 22 acres had arsenic and/or lead concentrations above 1000 parts per million (ppm) and 13 acres had concentrations greater than 100 ppm;
- Chromium was found near hide residues and the chromium lagoons; about 5 acres had chromium concentrations above 1000 ppm and 5 other acres had concentrations above 100 ppm;
- Barium, copper, and zinc were found in most areas of the site at concentrations greater than 100 ppm and in the same areas where arsenic, lead, and chromium were found; and
- Mercury concentrations above 100 ppm were found in a few locations, always associated with high lead levels.

Figure 4-1b presents maps showing the distribution of heavy metals prepared by Stauffer based on the subsurface investigation summarized above. Figure 4-1b (top map), arsenic and lead concentration contours, shows the prevalence of these two heavy metals across the Industri-plex Site. Figure 4-1b (middle map), chromium concentration contours, shows a smaller areal extent with high concentrations, including areas near the East-Central and East Hide Piles as well as the former chromium lagoons. Figure 4-1b (bottom map), copper and zinc concentration contours, shows the “widespread” areas described in the report (Stauffer, 1983). The areas of the site shown on the three contour maps were covered as part of the Industri-plex Site soil cover remedy completed in 1998.

Four large stockpiles of hide residues and other waste deposits were identified and estimated to cover approximately 8 acres (Stauffer, 1983). These stockpiles, also referred to as hide piles, include the East and West Hide Piles mentioned above, and the East-Central and South Hide Piles, located in areas not disturbed by the development activities. The hide piles were a source of nuisance/odorous air emissions of hydrogen sulfide and combustible gases. The hide piles were also covered as part of the Industri-plex Site soil cover remedy;

4.1.1.3 Potential Sources Identified in the Preliminary MSGRP Report

The Preliminary MSGRP Report identified and evaluated summaries of more than 25 sites located within the Northern Study Area that may be considered potential sources of environmental contamination to the Aberjona Watershed. As documented through research of site files at MADEP, these sites have had one or more of the following Industri-plex COCs present at elevated levels, in one or more environmental media: arsenic, chromium, lead, mercury, benzene, toluene, TCE, PAHs, and total petroleum hydrocarbons (TPH) (HNUS, 1997). The research also identified sites where COCs were discovered during routine property transfers or site development activities where the contaminants could not be attributed to previous site operations. In these situations, contamination was typically found at depth, either in overburden soils or groundwater, suggesting possible off-site sources.

The information summarized in the Preliminary MSGRP Report was used to focus future investigations conducted under the MSGRP RI in order to identify potential contaminant sources located outside the boundaries of the Industri-plex Site that may be impacting the MSGRP RI Study Area. Based on the findings of the Preliminary MSGRP Report, the following areas were incorporated into the additional MSGRP RI investigations conducted by TtNUS and described in Section 2.2.2.4.

Lake Bed of the Former Mishawum Lake

In the past, Mishawum Lake served as a sediment deposition area for surface water from Halls Brook and the Aberjona River. The reaches of the river and streams upstream of Mishawum Lake received runoff from industrialized sites, including the Merrimac Chemical Company (Industri-plex Site).

During the 1970s, a large portion of Mishawum Lake was filled to support area-wide development. Construction activities in the 1980s led to the discovery of soils and peat deposits contaminated with arsenic, chromium, and lead. Subsequent investigations identified these metals, plus mercury and TPH in lake bed sediments; arsenic and TCE were found in groundwater. The contamination was located at the approximate depth of the former lake bed, suggesting potential impacts resulting from discharges from Halls Brook or past chemical company operations (HNUS, 1997). This area was investigated further for the MSGRP RI to determine the potential presence of elevated concentrations of heavy metals in soils, groundwater, and surface water in the area of the former lake bed. The investigations completed in this area (Figure 4-1a, Site 4) are described in Section 2.2.2.4 of this report.

East Drainage Ditch

The East Drainage Ditch is a surface water drainage system that historically and currently receives runoff from several industrial sites (Figure 4-1a). Many of the nearby industrial sites are MADEP/MCP disposal sites and are on-going sources of soil and groundwater contamination. During its operation, the Olin Chemical plant in Wilmington (Figure 4-1a, Site 2) disposed of wastes, including acids, sulfates and chlorides, in lagoons and acid pits on site. As discussed in Section 4.1.2.3 below, surface water with high levels of chromium discharged from the former Olin Chemical plant to the East Drainage Ditch. Other industries upgradient of the Industri-plex Site whose operations may have discharged to the East Drainage Ditch include Raffi & Swanson, Inc., Ritter Trucking, and E. C. Whitney & Son, all located in Wilmington (HNUS, 1997).

Impacts to the East Drainage Ditch from potential contaminated groundwater discharges or from surface runoff from these sites were evaluated in the MSGRP RI groundwater investigation in Area A (described in Section 2.2.2.4). The sediment investigation described in Section 2.2.2.1 evaluated whether contaminated sediments are present as a potential on-going source of contamination to downstream receptors such as Halls Brook, HBHA, and the Aberjona River.

Allstate Sand and Gravel Dump

Historical records maintained by the Woburn Board of Health indicate that the Allstate Sand and Gravel Dump was a continuing source of pollution to groundwater, the Aberjona River, and Mishawum Lake during its period of operation (1953 to 1965). The records do not clearly identify the exact locations where dumping and burning occurred (HNUS, 1997). TtNUS conducted the investigation described in Section 2.2.2.4 at “Area G”, Site G-1, located south of the former dump (Figure 4-1a), to determine if contamination remains at the site and to evaluate potential impacts to on-site groundwater, downgradient areas, and surface water and sediment in the HBHA.

Sites Surrounding the Industri-plex Site

The Industri-plex Site is surrounded by various disposal sites where contamination sources are known to exist. The investigation and remediation of these sites is currently regulated under the MCP. Rather than extend future investigative efforts to each of the disposal sites, TtNUS adopted an area-wide investigative approach to evaluate impacts to the ultimate downgradient receptors. This approach, in addition to EPA’s decision to extend the MSGRP RI study area to include the Aberjona River Study, led to completion of a supplemental study to the Preliminary MSGRP report, titled “Preliminary MSGRP Supplemental Report – Southern Area. Other potential contamination sources that may contribute to surface water or sediment contamination in the Southern Study Area are discussed in Section 4.1.3 below.

4.1.1.4 Potential Sources Identified by Other Investigations

Table 4-1 provides general information about the potential sources discussed below, including dates of operation, type of industry, chemical used and products produced, and potential contaminants.

Olin Chemical - The Olin Chemical plant in Wilmington, MA (Figure 4-1a) was operated as a specialty chemical plant between 1953 and 1986. The facility was initially operated by National Polychemicals (1953-1968), then by Stephan Chemical Company (1968-1980), and finally by Olin Chemical (1980-1986). Lagoons, acid ponds and a landfill on the property resulted in soil, groundwater and surface water contamination, including discharges to the East Drainage Ditch.

Site contaminants include arsenic, chromium, and lead in groundwater and surface water, and chromium in site soils and sediments (HNUS, 1997). Investigations in the early 1990s found chromium concentrations up to 5,000 ppm in site soils and 13,800 ppm in site sediments (HNUS, 1997). MADEP documented the presence of a “chromium-containing floc” migrating into the East Drainage Ditch from the site via a surface water route (MADEP, 2002).

A 1955 aerial photograph included in an Olin submittal to MADEP showed a surface water drainage ditch crossing the Olin property from west to east, discharging into the North Pond. There appeared to be a hydraulic connection and contaminant migration pathway along the drainage ditch and to the North Pond for approximately 30 years, until 1982. In 2002, MADEP required Olin to conduct an investigation of the apparent migration pathway. Data from one North Pond sediment sample indicated the presence of ammonia, chloride, sulfate, chromium, and bis(2-ethylhexyl)phthalate, all contaminants associated with the Olin operations (MADEP, 2004). A concentration of trivalent chromium of 1,260 mg/kg was found in the pond sediment sample (MADEP, 2004). These contaminants were also detected in some of the site groundwater monitoring wells. At MADEP's direction, Olin is completing a further investigation of sediments in North Pond to determine whether contaminants from the Olin property are present in the sediments and also investigate a potential contaminant migration pathway from the west side of the plant down New Boston Road and discharging into Halls Brook.

Ritter Trucking Company - A number of site assessments and investigations have been completed for the Ritter Trucking Company property in Wilmington, MA (Figure 4-1a). The property is approximately 1 mile north of the Industri-plex Site. Wash water from the truck washing operations was collected in three UST/settling tanks; effluent was discharged to the MDC sewer. The settling tanks were known to overflow and spill resulting in groundwater and soil contamination. The operations on the property between 1961 and the late 1980s were found to have contaminated the MDC sewer line (Weston, 1998a). Hazardous wastes including waste oils, motor oils, diesel fuel, flammable liquids, and latex were identified during the investigations; acetone, toluene, and bis(2-ethylhexyl)phthalate were disposed on the site and are considered to be site contaminants (Weston, 1998a).

Groundwater samples contained the following heavy metals that were partially attributed to site operations: arsenic (11 to 17 ppb); copper (112 to 159 ppb); and lead (14.9 to 17.4 ppb) (Weston, 1998a). Surface water samples contained arsenic and toluene (Weston, 1998a).

Sediment samples from the stormwater drainage system and a drainage ditch west of the property (which appears to empty into the East Drainage Ditch) contained acetone, toluene, PAHs, cadmium, copper, and lead. Site surface water runoff drains into North Pond; site groundwater appears to discharge to the East Drainage Ditch (Weston, 1998a).

4.1.2 Southern Study Area Sources

TtNUS's Preliminary MSGRP Supplemental Report - Southern Area identified and reviewed available MADEP, CERCLIS and other information on 52 sites that were: within the Southern Area boundaries; that had the potential for contaminants to reasonably impact the Aberjona River based on their location; and had reported releases of COCs (arsenic, lead, chromium, benzene, mercury, TCE, etc.) (TtNUS, 2003).

Tanneries, leather finishing companies, renderers, chemical manufacturers, landfills, and metal fabricators operated since the early 1800s in the portions of Woburn and Winchester that are within the Southern Study Area. These industries often disposed of liquid waste in on-site lagoons and disposed of sludge, hides and other solid materials in on-site landfills. Historically, their operations may have contaminated groundwater, surface water, and/or sediments within the Aberjona River watershed. Industrial activities are currently concentrated in the southwest part of Woburn and the northern part of Winchester. In addition, facilities with leaking underground storage tanks may have also contributed to contamination in the watershed.

Confirmed sources of contamination in the Southern Study Area are regulated under both CERCLA and the MCP. Information is presented below for both the CERCLA and MCP sites that are considered confirmed sources of contamination based on the information summarized in the Preliminary MSGRP Supplemental Report - Southern Area. Table 4-1 provides general information about the potential sources, including dates of operation, type of industry and products produced, and potential contaminants. These potential sources are shown on Figure 4-1a.

4.1.2.1 Wells G&H Site

The 1989 ROD for the Wells G&H Site specified a remedy for Operable Unit 1 (OU-1) and designated two other operable units. The Wells G&H Source Area (OU-1) includes five Source

Area properties that were identified as confirmed sources of contamination (Figure 4-1a). Remedial actions are underway at four of the five Source Area properties. In the Wells G&H Central Area (OU-2), remedial investigations are continuing to evaluate the condition of the Aberjona River aquifer outside of the OU-1 Source Areas, with particular emphasis on the Southwest Properties. In addition to these eight confirmed CERCLA sites, five MCP sites were identified as potential sources of contamination as discussed below.

The soil and groundwater in the five source area properties were contaminated with VOCs: specifically TCE, PCE, vinyl chloride, and 1,1,1-TCA (TtNUS, 2003). SVOCs, metals, and other inorganics were not considered to be contaminants of concern. Groundwater extraction and treatment systems have been operating at the Unifirst, W.R. Grace, and Wildwood Property source areas (Figure 4-1a) to remediate the VOCs in groundwater. Soils at the Unifirst and W.R. Grace sites did not contain significant contamination; soils containing PAHs, PCBs, organic pesticides, VOCs and metals were excavated and removed from the Wildwood Property (TtNUS, 2003). Surface soils at the New England Plastics property (Figure 4-1a) containing PAHs, PCBs, TCE and PCE were excavated and disposed of offsite; other areas of soil contamination were treated by soil vapor extraction over a period of approximately 16 months (TtNUS, 2003). Two Administrative Orders are now in place between EPA and the Olympia Nominee Trust (Figure 4-1a) to: 1) remove soils contaminated with PAHs, PCBs and TCE; and 2) treat soils contaminated with TCE in different portions of the property.

Three properties, Murphy Waste Oil, Aberjona Auto Parts and Whitney Barrel, known as the Southwest Properties, are the focus of the Central Area aquifer study (OU-2) for the Wells G&H Site (Figure 4-1a). A remedial investigation was performed in 1994 but due to data gaps, no risk assessment was completed. Groundwater contaminants at the Murphy Waste Oil property include VOCs and SVOCs; wetland sediment contained pesticides, PCBs, and lead; soils contained chlorinated VOCs, PAHs, BTEX, PCBs, chromium, and lead (TtNUS, 2003). The primary contaminants found in surface and subsurface soils at the Whitney Barrel property included PAHs, PCBs, metals, and BTEX (TtNUS, 2003). Surface and subsurface soils at the Aberjona Auto Parts property contained PAHs, BTEX, chromium, and lead; the primary groundwater contaminant was TCE (TtNUS, 2003). Once additional data are collected, EPA will complete a risk assessment for the three Southwest Properties.

4.1.2.2 Potential Sources Identified in the Preliminary MSGRP Supplemental Report

The MCP sites and other non-point sources of potential contamination included in the Preliminary MSGRP Supplemental Report - Southern Area are discussed below. It is important to note that investigations performed under the MCP do not typically extend beyond the individual site property boundaries, leaving the extent of potential off-site contamination and downgradient impact undefined. Therefore, the actual contribution of these potential sources to Aberjona River watershed contamination cannot be clearly defined. Very little surface water and sediment data were available from the MADEP site files. However, other Industri-plex and Wells G&H field investigation reports and MIT research publications have presented data indicating that elevated levels of arsenic, chromium, and lead have been detected in sediments throughout the Southern Study Area.

The supplemental MSGRP report identified the following five sites in the Southern Study Area as potential sources of contamination to the Aberjona River. Table 4-1 provides general information about the potential sources, including dates of operation, type of industry and products produced, and potential contaminants.

J.O. Whitten Property - J.O. Whitten in Winchester (Figure 4-1a), was a former tannery and rendering plant. Wastes from these operations were disposed of on the site in open pits and lagoons. A 1997 site reconnaissance found pits containing a lime sludge residue and scrap hides, coal slag, and a landfill near the Aberjona River with arsenic, chromium and cyanide-containing sludge. Soil, groundwater and/or surface water samples collected from this site contained arsenic, chromium, mercury, lead, cyanide, benzene, and toluene (TtNUS, 2003). The highest concentrations of metals found in soil borings completed in 2000 during a site inspection were: 353 ppm arsenic at a depth of 9–11 feet; 498 ppm lead at 0-2 feet; and 338 ppm chromium at 4-6 feet (Weston, 2001). A site inspection completed in the late 1990s concluded that there had been a release of hazardous substances to the Aberjona River from the site and that river sediments and wetlands contained elevated concentrations of metals (arsenic, copper and mercury) associated with the site (Weston, 2001). Sediment samples from the river contained maximum concentrations of 490 ppm arsenic and 1410 ppm copper. The site is listed in the CERCLIS database as a state-lead cleanup.

Independent Tallow Co., Inc. - Independent Tallow in Woburn (Figure 4-1a) was the site of tannery operations and tallow and crackling production. Disposal of hides, solid wastes and drums has been documented on the site. Heavy metals were found in test pits, soils and borings; high levels of chromium were found in the wetlands on the edge of the site. Soils, primarily from wetland areas and contaminated with arsenic, chromium, and mercury, were removed from the site in 2000 (Vertex, 2000). Additional work was begun in April 2001 to reduce risks associated with PAHs and metals in soils in the southern portion of the site and allow for the development of the site for residential apartment use.

Atlantic Gelatin (Kraft Foods) - Atlantic Gelatin has operated as a gelatin processing plant in Woburn for 85 years (Figure 4-1a). Process sludge was initially disposed of at an on-site landfill and in the 1980s was taken to the Woburn sanitary landfill. A number of spills, primarily fuel oils, have been documented at the plant (TtNUS, 2003). There are seven production wells on the property for process water supply; three are currently inactive. Numerous investigations have been conducted: fuel oil, LNAPL, PAHs and metals have been identified in various media at this site. No water quality data for these wells were available. The site is listed in the CERCLIS database as a state-lead cleanup.

American Shoe Machinery, (now Custom Machine, Inc.) - The following contaminants were found in soil and groundwater samples collected from this site in Woburn (Figure 4-1a): arsenic, chromium, lead, and TCE (TtNUS, 2003).

Crane's Court Industrial Park LLC - The following contaminants were found in soil and groundwater samples collected from this site in Woburn (Figure 4-1a): arsenic, chromium, mercury, and lead (TtNUS, 2003).

4.1.2.3 Other Potential Sources

Investigations conducted for use in the planned risk assessment for the Southwest Properties (see Section 4.1.3.1) identified elevated concentrations of chromium, lead, arsenic, and PCBs in sediments in wetlands on the Murphy Waste Oil property. To assist in the identification of the source of these metals, a site reassessment was completed by EPA in 2004 on the former J.J. Riley Tannery property which is upstream of the Murphy Waste Oil Property. The following maximum concentrations of metals were found in soil samples from the Riley property: 49,000

mg/kg chromium; 102 mg/kg copper; 637 mg/kg lead; and 109 mg/kg vanadium (Weston, 2004). Sediment samples collected from the Riley property contained organic pesticides, PAHs, ketones, and metals, including chromium, copper, lead, and zinc (Weston, 2004). The concentration ranges for the metals were: 386 to 47,100 mg/kg chromium; 29.1 to 124 mg/kg copper; 32.7 to 3110 mg/kg lead; and 7.2U to 1540 mg/kg zinc (Weston, 2004).

High levels of lead have been found in sediments in the Wells G&H wetland and on the adjacent property owned by the Massachusetts Rifle Association (MRA) (TtNUS, 2003). The MRA has been operating as a sportsman's club and shooting range for over 125 years and claims to be the oldest of its kind in the United States. Outdoor shooting ranges at this club currently include a 200 yard rifle range and of particular note, a trap field and sporting clays shotgun range. While the rifle range target area is confined by an earthen backstop/berm, the shotgun range is open causing a broader distribution of lead pellets over a greater area. In response to nationwide environmental concerns, particularly the protection of waterfowl that are typically poisoned by ingesting lead shot, the MRA recently joined other gun clubs and associations around the country by requiring the use of steel shot ammunition on their ranges instead of the traditional lead shot. However, this is only a recent change and historically, lead shot has been the principal component of shotgun ammunition. Although the actual amount of lead deposited in the environment depends on the number and frequency of shooting events, the number of participants involved, and the actual ammunition used, the MRA still represents a potential historical source for lead in the environment.

The use of lead arsenate to control vegetation on railways has also been linked to the elevated lead and arsenic residues in soils within the MBTA's right-of-way (TtNUS, 2003).

Potential Non-point Sources: Non-point sources of contamination in the Southern Study Area may have some impact on the Aberjona River watershed. Potential non-point sources of contamination include: sewer overflows; historical use of arsenic- and lead-based pesticides; runoff from the roadways and highly developed areas; traffic accidents and spills; and fertilizer application. During the period from approximately 1910 until the late 1940s, sewer overflows were potential sources of non-point pollution in the City of Woburn. Trunked sewers were identified in the ROD as a potential a concern for continued contamination source too. However, under the GSIP Phase I investigations, it was concluded that these trunk sewer systems did not represent a source of contamination to the watershed or aquifer.

Historically, arsenical pesticides were manufactured within the Aberjona River watershed at Merrimac Chemical Company. By 1899, Merrimac Chemical Company was one of the largest producers of lead arsenate in the United States, and reached peak production by 1918 (TtNUS, 2003). Arsenic-based pesticides were used in the watershed for control of gypsy moths and for agricultural applications, including orchards.

The use of arsenic-based pesticides within the United States began in the late nineteenth century, and decreased by the late 1940s to the early 1950s due to the introduction of DDT. Arsenic-based insecticides included: copper arsenate or “Paris Green”; calcium arsenite or “London Purple”; and lead arsenate. Due to its carcinogenicity, the EPA banned the use of lead arsenate as an insecticide on August 1, 1988 (EPA, 1988).

In 1890, Paris Green was sprayed from May to July within the Southern Area to control gypsy moth infestations. In 1895, the Middlesex Fells Reservation (immediately east of the Southern Area) was used as an experimental area for lead arsenate application (TtNUS, 2003). Auditor reports for the Town of Winchester and Cities of Medford and Woburn from 1902 to 1970 indicated that their gypsy moth control departments consistently purchased “arsenate of lead” beginning in 1906 and continuing through at least 1947, with some recorded purchases from Merrimac Chemical Company (TtNUS, 2003). There were no records available as to the quantities purchased or the amounts applied.

An apple orchard operated in south Wilmington, just north of the Industri-plex study area during the late 1700s and 1800s as part of the Butter’s family farm. Although there are anecdotal references to other apple orchards in the area, no records have been located to confirm their presence or the use of arsenic-based pesticides (TtNUS, 2003).

During the 1970s, the Boston and Maine railroad used monosodium methane arsenate (MSMA) as a herbicide along the railroad tracks which run north - south through the Southern Area (Geotrans, 1987). The quantities used and specific locations in which MSMA was applied within the Southern Area are not known. The June 2001 Release Abatement Measure (RAM) Completion Report prepared for the Massachusetts Bay Transportation Authority (MBTA) noted that it was common practice of the MBTA to apply lead arsenate on railways as a herbicide (BATG Environmental Inc., 2001). In addition, lead arsenate was used commercially in

orchards, and its use peaked in the 1940s. No records were available that documented its use in orchards in the Southern Study Area.

4.2 Soils Contamination

As described in Section 2, several investigations have been conducted by the ISRT, EPA, and TtNUS to determine the nature and extent of contamination present in study area soils. This section presents the evaluation of analytical data collected during those investigations. The evaluation of the nature and extent of soil contamination is divided into four groups according to location and sampling rationale: Industi-Plex site perimeter soils, former Mishawum Lake bed soils, benzene and toluene source area soils, and floodplain soils. The nature and extent of soils contamination in the study area are evaluated in relation to the comparison concentrations identified in Section 4.2.1 to assess whether contaminant concentrations detected in site media are elevated relative to reference values.

The analytical data for samples in each area are compared to the reference criteria to identify areas of contamination that may pose a threat to human health or the environment. The narrative and tables presented in Sections 4.2.2 through 4.2.5 identify exceedances of the individual criteria. In order to identify the areas that have the highest level of contamination and may pose the greatest threats, the accompanying figures highlight the sample locations where detected contaminants exceed all applicable criteria for protection of human health and the environment and exceed the average background concentrations for the study area.

4.2.1 Soil Comparison Criteria

To assess whether contaminant concentrations detected in site media are elevated relative to accepted reference values, it is necessary to compare the concentrations detected in samples collected from the site with appropriate reference concentrations. For Study Area soils, three sets of reference values were used:

- US EPA Region 9 Preliminary Remediation Goals (PRGs) for Residential Soil (EPA, 2004) – The Region 9 PRGs are concentrations of potential human health concern developed by EPA Region 9 for nearly 600 chemicals in various media. The values were calculated based on target risk levels of 1×10^{-6} for potential carcinogens or a

hazard quotient (HQ) of 1 for noncarcinogens, using reasonable maximum residential exposure assumptions. Although many of the soil investigation areas are in industrial or commercial areas, the PRGs for residential soil (instead of industrial) were used throughout the study area to be protective of recreational exposure by adolescents, which would not be addressed by the PRGs for industrial soil. The PRG for lead is set at the residential soil screening level of 400 mg/kg (EPA, 1994); the PRG for chromium III is used for chromium; the PRG for methylmercury is used for mercury; and the most conservative PRG of all non-carcinogenic PAHs (naphthalene) is used for acenaphthalene, benzo(g,h,i)perylene, and phenanthrene.

- MADEP Background Levels of Polycyclic Aromatic Hydrocarbons and Metals in Natural Soil (MADEP, 2002b) – MADEP has selected and published background PAH and metals concentrations for natural soil and for soil containing either coal ash or wood ash associated fill material. The background values are intended for use as a screening tool to streamline risk characterization in the absence of site-specific background concentrations. In this RI, the values for natural soil have been used for comparison because no specific information is available to show that the soil in the RI study area contains wood ash or coal ash associated fill material.
- Industri-plex Site ROD Action Levels for Contaminated Soils (EPA, 1986) – These values were used in the Industri-plex ROD to identify soils that required remedial action (capping with 30 inches of cover materials). The action levels were established for three site soil contaminants: arsenic (300 ppm), chromium (1000 ppm), and lead (600 ppm). These action levels were established in the Endangerment Assessment as being protective of public health and welfare and the environment (EPA, 1986). In this RI, the action levels are used as reference concentrations only for the soils samples collected at the perimeter of the IP site, to determine whether metals contamination above the action levels extends outside the boundaries of the soil cover.

The analytical data for samples in each area were compared to the applicable reference criteria to identify areas of contamination that may pose a threat to human health or the environment. The narrative and tables presented in Sections 4.2.2 through 4.2.5 identify exceedances of the individual criteria. In order to identify the areas with the highest level of contamination, which may pose the greatest threats to humans health and the environment, the accompanying figures

highlight the sample locations where detected contaminants exceed all available criteria, including the criterion established for protection of human health (Region 9 PRG). This eliminates analytes that exceed only the average background concentrations. Exceedances of the Industri-plex Site ROD Action Levels, which were only evaluated for the Industri-plex Site soil cover perimeter soil samples, are identified separately from other criteria to ensure that the basis for identifying exceedances of “all available criteria” is consistent across all soil sample groups.

4.2.2 Industri-plex Site Soil Cover Perimeter

Soils at four properties along the perimeter of the Industri-plex Site (Area 2- Dundee Park, west of West Hide Pile; Area 5b – north of Boston Edison ROW; Area 6 – south of the Boston Edison ROW, east of the B&M Railroad ; Area 7 – west of B&M Railroad, south of Boston Edison ROW) were investigated by TtNUS in August and September 2000 to determine whether metals contamination in soils extended beyond the limits of the soil cover (indicated on Figure 4-1b). Samples were collected at 30 locations on the four properties. At most sample locations, soils were collected in 1-foot intervals from the ground surface to a depth of 3 feet bgs. At five locations the third depth interval sample was not collected because refusal was encountered at approximately 2 feet bgs. A total of 85 samples were collected. All samples were analyzed for total metals; 15 of the samples (a subset of the samples from each property) were also analyzed for hexavalent chromium and sulfides. The analytical results are discussed below. See Section 2.2.2.3 and Table 2-9 for additional details of investigation methods. Summary statistics and comparisons to reference concentrations are presented in Table 4-2a. Complete analytical data for soils are presented in Appendix 4A. Sample locations where contaminant concentrations exceeded applicable reference criteria are shown on Figure 4-2a and 4-2b.

The analytical data from the site perimeter soil samples were compared with the Industri-plex Site ROD action levels for contaminated soils, EPA Region 9 PRGs for residential soil, and MADEP background soil concentrations for natural soil. In general, the highest concentrations of contaminants and the most numerous and widespread exceedances of the comparison criteria occurred in the samples from Area 6 locations 06 through 13. Soil samples from all depth intervals at locations A606 through A613 consistently exceeded the comparison criteria for arsenic, chromium, and lead as well as numerous other metals. Metals concentrations in some samples from the other Area 6 locations and samples from Areas 2, 5, and 7 also

exceeded comparison criteria for selected metals, but the concentrations were typically lower and exceedances less widespread. Figures 4-2a and 4-2b show the Industri-plex Site soil perimeter sample locations where all applicable criteria were exceeded. Details of comparison criteria exceedances are described below.

Industri-plex Site soil action levels for arsenic, chromium, and lead were exceeded exclusively at Area 6 sample locations. As shown on Table 4-2a, arsenic concentrations exceeded the action level in 14 samples (at A6 locations 06, 07, 08, 09, 11, 12, and 13); chromium exceeded the action level in 5 samples (at A610 and A611) and lead exceeded the action level in 20 samples (at A606 through A613). For all three contaminants, exceedances occurred in samples from all three depth intervals.

EPA Region 9 PRGs for residential soil were exceeded for six metals in the Industri-plex Site perimeter soil samples (antimony, arsenic, iron, lead, mercury, and thallium), as shown on Table 4-2a. For arsenic, lead and thallium the average concentration for the sample group also exceeded the criteria. The maximum detected concentrations of arsenic and lead were more than 10 times higher than the criteria. The Region 9 PRG for arsenic was exceeded in all 85 soil samples collected. The PRG for thallium was exceeded in 48 of the 85 samples, with exceedances occurring in all areas, but the highest concentrations and most widespread exceedances in Area 6 locations 06 through 13 and Area 7 locations 01 through 07. The remaining exceedances occurred primarily in samples from Area 6 locations 06 through 13. Most samples from these locations exceeded the criteria for iron and lead. Antimony and mercury concentrations also exceeded the PRGs at isolated locations in Area 6.

MADEP background soils concentrations were exceeded for 18 metals in the Industri-plex Site perimeter soil samples, as shown on Table 4-2a. For 12 of these metals, including arsenic, chromium, and lead, the average concentrations for the sample group also exceeded the criteria; for 10 metals, including arsenic, chromium, and lead, the maximum detected concentration was more than 10 times higher than the background concentration. The largest number of exceedances occurred in Area 6, with fewer exceedances in samples from Areas 2, 5, and 7. Most samples from Area 6 locations 06 through 13 exceeded the background soil concentrations for antimony, arsenic, barium, chromium, cobalt, copper, iron, lead, mercury, selenium, silver, and zinc. Limited exceedances of cadmium, manganese, and vanadium also occurred in Area 6 samples. The background concentration exceedances in Area 6 were

identified in samples from all depth intervals. Limited exceedances of background concentrations for aluminum, arsenic, barium, chromium, iron, magnesium, silver, vanadium, and zinc were also noted in Area 2 samples from various depths. Limited exceedances of background concentrations for arsenic, chromium, and zinc were also noted in Area 5 and Area 7 samples from various depths. Cobalt and copper concentrations exceeded the MADEP background concentrations in samples from various depths at most A2 and A7 locations. Selenium concentrations exceeded the MADEP background concentrations in samples from various depths at most A2, A5, and A7 locations. Thallium exceeded the MADEP background concentrations in 72 of the 85 samples – at least one depth interval at nearly all sample locations from every area.

Figures 4-2a and 4-2b show the Industri-plex Site soil perimeter sample locations where all applicable criteria were exceeded. Six metals (arsenic, antimony, iron, lead, mercury, and thallium) exceeded both the EPA Region 9 PRGs and MADEP background concentrations. Most sample intervals in A605 through A613 exceeded both of these criteria for arsenic and more than half also exceeded the Industri-plex soil action levels for arsenic. Only a few samples from the other areas exceeded applicable criteria for arsenic. Area 6 samples also dominated the exceedance of applicable criteria for other metals, as shown on Figure 4-2b. Nearly all the locations exceeding the Region 9 PRGs and MADEP background concentrations for lead also exceeded the Industri-plex soil action levels. Although chromium concentrations in five samples exceeded the Industri-plex soil action levels, none exceeded the EPA Region 9 PRGs.

4.2.3 Former Mishawum Lake Bed Soil Cores

Soils in the area of the former Mishawum Lake bed were investigated by Roux for the ISRT in May 2001 to determine whether site-related contaminants were present in the area of the former lake. Soil samples were collected continuously from the ground surface to the bottom of the former lake bed at 20 locations. At most locations, two soil samples were collected for analysis: one from the surface (0 to 1 feet bgs) and one that spanned the peat/sediment layer at the bottom of the now-filled former lake bed. At five locations, lake bed deposits were not found and only a surface sample was collected. The soil samples were analyzed for TAL metals, mercury, TCL SVOCs, and VOCs. See Section 2.1.5.2 and Table 2-1 for additional investigation details. Sample locations are shown on Figure 2-3a. The analytical results are

discussed below. Summary statistics and comparisons to reference concentrations are presented in Table 4-2b. Complete analytical data for soils are presented in Appendix 4A. Exceedances of reference concentrations are shown on Figures 4-2a, 4-2b, and 4-2c.

The analytical results from the former Mishawum lake bed soil samples were compared with the EPA Region 9 PRGs for residential soil and the MADEP background concentrations for natural soil. The surface soils and lake bottom soils were also compared against each other.

In general, the surface soil samples had higher concentrations of SVOCs, higher frequencies of detection for individual SVOCs, and more exceedances of comparison criteria. The average and maximum SVOC concentrations were typically an order of magnitude higher in the surface soil samples than in the bottom samples. The lake bottom soil samples generally had higher concentrations of metals and more exceedances of the comparison criteria for metals. The average and maximum concentrations for most metals were typically less than an order of magnitude higher in the bottom samples than in the surface soil samples. A few metals, including arsenic, antimony, and cadmium were more than an order of magnitude higher in the bottom soils. VOCs concentrations in the lake bottom samples were generally more than an order of magnitude higher than in the surface soil samples; no VOCs exceeded comparison criteria in the surface or lake bottom samples. Figures 4-2a, 4-2b and 4-2c show the soil sample locations where all applicable criteria were exceeded. Details of the data comparison against reference concentrations are discussed below, by analyte group.

4.2.3.1 Metals – Mishawum Lake Bed Soil Cores

Seven metals (arsenic, antimony, cadmium, iron, lead, mercury, and thallium) exceeded both the EPA Region 9 PRGs and MADEP background concentrations in at least one soil core sample (see Figures 4-2a and 4-2b). Arsenic exceeded both applicable criteria at 13 locations – seven of these had exceedances in both surface and lake bed samples, one only in the surface sample, and four only in the lake bed sample. Most of the exceedances of all applicable criteria for other metals occurred in the lake bed sample from a single location (SO-13). The details of the analytical results and criteria comparisons for metals in surface and lake bottom soil samples are discussed below.

Surface Soils

The highest metals concentrations and most frequent exceedances of comparison criteria for metals generally occurred in surface soil samples from SO-13, -14, -15, -16, and -18.

The Region 9 PRG for residential soil was exceeded only for arsenic. The criteria was exceeded in all 20 surface soil samples.

MADEP background soils concentrations were exceeded for 16 metals in surface soils in the area of the former Mishawum Lake, as shown on Table 4-2b. For six of these metals (arsenic, chromium, cobalt, copper, mercury, and selenium) the average concentration also exceeded the criteria; these six metals were the only ones that exceeded the background criteria in more than 5 of 20 samples. Most sample locations had exceedances of at least one metal. Several locations in the center of the former lake bed area (SO-09, -13, -14, -15, -16, and -18) exceeded the background criteria for multiple metals including the six identified above.

Lake Bottom Soils

The highest metals concentrations and most frequent exceedances of comparison criteria for metals generally occurred in bottom soil samples from SO-03, -11, -13, and -16. The maximum concentration of most metals occurred at SO-13.

The Region 9 PRGs for residential soil were exceeded for seven metals (antimony, arsenic, cadmium, iron, lead, mercury, and thallium) in the lake bottom soils. Most of these metals exceeded the criteria at only one or two locations. Arsenic exceeded the criteria in all 15 samples and had an average concentration higher than the PRG.

MADEP background soils concentrations were exceeded for 20 metals in the lake bottom soils, as shown on Table 4-2b. The average concentrations of 11 of these metals (antimony, arsenic, cadmium, chromium, cobalt, copper, lead, mercury, selenium, thallium, and zinc) also exceeded the criteria. All of these metals except cadmium, lead, and selenium exceeded the background criteria in more than half of the samples. All bottom sample locations had background exceedances by at least one metal. Locations with the most metals exceeding background criteria were SO-03, -08, -09, -11, -13, -14, -16, and -17.

4.2.3.2 SVOCs – Mishawum Lake Bed Soil Cores

Five PAHs (benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene) exceeded both the EPA Region 9 PRGs and MADEP background concentrations in the surface soil sample at SO-09 (see Figure 4-2c). No other SVOCs exceeded all available criteria in any other surface or lake bed sample. The details of the analytical results and criteria comparisons for SVOCs in surface and lake bottom soil samples are discussed below.

Surface Soils

As shown on Table 4-2b, a total of 19 SVOCs, predominantly PAH compounds, were detected in the surface soil samples in the area of the former Mishawum Lake. The SVOC concentrations in most samples were low in comparison to reference concentrations.

Region 9 PRGs were exceeded for five PAH compounds in the surface soil samples. The maximum concentrations of each of these compounds was detected in the sample from SO-09. Most of the compounds were detected at three or fewer locations, only benzo(a) pyrene was detected more frequently.

Eleven of the compounds, all PAHs, were detected at concentrations exceeding MADEP background soils criteria at one location (SO-09). Most of these compounds were detected in at least half of the samples at concentrations lower than the background criteria. Most of the remaining SVOCs, which did not exceed the background criteria, were detected in only a few samples.

Lake Bottom Soils

As shown on Table 4-2b, a total of 15 SVOCs, predominantly PAH compounds, were detected in the lake bottom soil samples. Most compounds were detected at only a few locations. The SVOC concentrations in most samples were low in comparison to reference concentrations. Region 9 PRGs were only exceeded for benzo(a) pyrene (in three samples), with the maximum concentration detected at SO-09. MADEP background soils concentrations were not exceeded for any compound.

4.2.3.3 VOCs – Mishawum Lake Bed Soil Cores

The analytical results for VOCs in surface and lake bottom soil samples are discussed below. No VOC exceeded the applicable comparison criteria.

Surface Soils

As shown on Table 4-2b, five VOCs were detected in the surface soil samples in the area of the former Mishawum Lake. Most compounds were detected at only a few locations; only acetone was detected in the majority of samples. The VOC concentrations in the surface soil samples were low in comparison to reference concentrations. No VOCs exceeded Region 9 PRGs. There are no MADEP background soils concentrations for VOCs.

Lake Bottom Soils

As shown on Table 4-2b, seven VOCs were detected in the lake bottom soil samples. Most compounds were detected at only a few locations; only acetone and 2-butanone were detected in the majority of samples. The VOC concentrations in the lake bottom samples were low in comparison to reference concentrations. No VOCs exceeded Region 9 PRGs. There are no MADEP background soils concentrations for VOCs.

4.2.4 **Benzene and Toluene Source Area Soils**

Soil samples were collected at the Vining property and West Hide Pile study areas by Roux for the ISRT in December 2002 to further investigate potential benzene and toluene source areas. Soil samples were collected from 17 boring locations on the Vining property study area (RX-1 through RX-17) and two boring locations at the West Hide Pile study area (RX-18 and RX-19). The boring locations were determined based on the results of soil gas and geophysics surveys at five source area properties, as described in the Final GSIP SOW source area reports in Appendices 2B-2, 2B-3, and 2B-4. Soil samples were collected continuously from the ground surface down to the water table and screened for VOCs in 2.5-foot sections using a photo-ionization detector (PID). The soil sample from the depth interval with the highest PID reading or, if no positive PID readings were observed, the interval immediately above the water table, was sent to a laboratory for analysis of benzene and toluene. At one location (RX-18), a

saturated soil sample was collected from the interval immediately below the water table due to elevated PID readings. See Section 2.1.5.1, Table 2-1, and Appendices 2B-2, 2B-3, and 2B-4 for additional investigation details. Sample locations are shown on Figure 2-3a.

The analytical results from the source area soil samples were compared only with the EPA Region 9 PRGs for residential soils. Background soil concentrations have not been developed by MADEP for VOCs.

The analytical results are discussed below. Summary statistics and comparisons to reference concentrations are presented in Table 4-2c. Complete analytical data for soils are presented in Appendix 4A. Exceedances of reference concentrations are shown on Figure 4-2c.

Vining Property Soils

As shown on Table 4-2c, benzene and toluene were both detected in most of the Vining Property soil samples. The compounds were detected at relatively low concentrations compared with reference criteria in most samples. The highest concentrations of both benzene and toluene were detected at four locations (RX-8, -9, -11, and 16). Only benzene exceeded the reference criterion.

Benzene was detected in 15 of 17 samples and exceeded the Region 9 PRG (600 ug/kg) in four samples (RX-8, -9, -11, and 16). Detected benzene concentrations were less than 50 ug/kg in nine of the remaining 11 samples. Toluene was detected in 11 of 17 samples, all at concentrations below the Region 9 PRG (520,000 ug/kg). Toluene concentrations at three locations (RX-8, -9, and -11) were significantly higher than in the remaining samples. The concentrations of these three ranged from 9,300 to 98,000 ug/kg, with the next highest (RX-16) at 280 ug/kg, and six of the remaining seven detected toluene concentrations less than 40 ug/kg. There are no MADEP background soil concentrations for VOCs.

West Hide Pile Soils

As shown on Table 4-2c, benzene and toluene were both detected in the three West Hide Pile soil samples. The compounds were detected at low concentrations (less than 15 ug/kg) in the two samples collected from unsaturated soils. Concentrations were significantly higher in the

sample collected immediately below the water table at RX-18 (RX-18-1015). The benzene concentration in the saturated zone sample exceeded the Region 9 PRG. The PRG for toluene was not exceeded. There are no MADEP background soil concentrations for VOCs.

4.2.5 Floodplain Soils

TtNUS and EPA NERL collected soils from several depositional areas of the floodplain adjacent to the HBHA and the Aberjona River between July 2000 and May 2004 to investigate the presence of metals deposited by floodwaters. At each sample location, soils were collected from the 0- to 0.5-foot depth interval and analyzed for total metals. Most samples were also analyzed for total organic carbon (TOC). Samples from one area (Davidson Park), were also analyzed for redox potential and sulfide.

The analytical results from the floodplain soil samples were compared with the EPA Region 9 PRGs for residential soils and the MADEP background concentrations for natural soil.

The analytical results are discussed below, by area, presented from north to south (upstream to downstream). Summary statistics and comparisons to reference concentrations are presented in Table 4-2d. Complete analytical data for soils are presented in Appendix 4A. Exceedances of reference concentrations are shown on Figures 4-2a through 4-2k.

As shown on these figures, arsenic was the most pervasive contaminant detected in floodplain soil samples. Arsenic concentrations exceeded all applicable reference criteria in at least half of the floodplain soil samples in all reaches where samples were collected (all reaches except 4 and 6). Iron also exceeded all criteria in all reaches, but only at one location in each reach. Three other metals (lead, manganese, zinc) exceeded all criteria at a few isolated locations in the study area.

4.2.5.1 Boston Edison Company (BECO) Right of Way (Reach 0)

Surface soil samples were collected from four locations (BSO-01 through BSO-04) on the embankment above drainage channels on the BECO right-of-way to investigate potential metals contamination deposited by flood waters. The samples were collected by EPA NERL in July 2002 and analyzed for total metals and TOC.

As shown on Table 4-2d, 22 metals were detected in the BSO samples. Most of the metals were detected in most or all samples. The Region 9 PRGs were exceeded for two metals. The PRG for arsenic was exceeded in all four samples and the PRG for iron was exceeded in one sample.

Most of the metals were detected at concentrations similar to or lower than MADEP background soil criteria for natural soils. Sixteen metals were detected at concentrations exceeding the background soil criteria; however, most of the metals (12) exceeded the criteria at only one location, the remaining four exceeded the criteria at two locations. The maximum concentrations detected were generally in the same order of magnitude as the background criteria. The highest concentrations and most of the criteria exceedances occurred in samples from BSO-01 and BSO-04.

As shown on Figures 4-2a and 4-2b, only arsenic and iron exceeded both applicable criteria in the BSO floodplain soil samples. Each exceeded the criteria at one location.

4.2.5.2 Halls Brook Holding Area (Reach 0)

Surface soil samples were collected from 10 locations (HB04-01 through HB04-10) along a dirt access road on the east side of the HBHA wetland to investigate potential metals contamination deposited by flood waters. The samples were collected by EPA NERL in July 2002 and analyzed for total metals and TOC.

As shown on Table 4-2d, 22 metals were detected in the HB04 samples. Most of the metals were detected in most or all samples. EPA Region 9 PRGs were exceeded only for arsenic. The criteria was exceeded in all 10 samples.

Most of the metals were detected at concentrations similar to or lower than MADEP background soil criteria. Eight metals were detected at concentrations exceeding the background criteria; however, the maximum concentrations detected were all in the same order of magnitude as the criteria. Generally, the highest concentrations of metals occurred in the sample from HB04-02.

As shown on Figures 4-2a and 4-2b, only arsenic exceeded both applicable criteria in the HBO4 floodplain soil samples. Arsenic concentrations exceeded the criteria at 6 of the 10 sample locations.

4.2.5.3 Normac Road (Reach 1)

Surface soil samples were collected from five locations (NR-16 through NR-20) along the bank of the Aberjona River in wetlands near Normac Road to investigate potential metals contamination deposited by flood waters. The samples were collected by EPA NERL in September 2002 and analyzed for total metals and TOC.

As shown on Table 4-2d, 21 metals were detected in the NR samples. Most of the metals were detected in most or all samples. The Region 9 PRGs were exceeded for arsenic in all five samples and for iron in one sample.

Most of the metals were detected at concentrations similar to or lower than MADEP background soil criteria. Fifteen metals were detected at concentrations exceeding the background criteria; however, the maximum concentrations detected were all in the same order of magnitude as the criteria. The maximum concentration of all analytes except sodium occurred in the sample from NR-20.

As shown on Figures 4-2d and 4-2e arsenic exceeded both applicable criteria in all five NR floodplain soil samples and iron exceeded both criteria in one sample. No other metals exceeded all applicable criteria.

4.2.5.4 Salem Street West Residence (Reach 1)

Surface soil samples were collected from five locations (WSS01 through WSS05) on a residential property on the west bank of the ponded area north of the Salem Street bridge to investigate potential metals contamination deposited by flood waters. The samples were collected by EPA NERL in July 2002 and analyzed for total metals and TOC.

As shown on Table 4-2d, 22 metals were detected in the WSS samples. Most of the metals were detected in most or all samples. The Region 9 PRGs were exceeded only for arsenic in all five samples.

Most of the metals were detected at concentrations lower than MADEP background soil criteria. The background criteria were exceeded for only three metals (cobalt, selenium, and thallium) at isolated locations. The maximum concentrations detected were only slightly greater than the criteria.

As shown on Figures 4-2d and 4-2e arsenic exceeded both applicable criteria in all five NR floodplain soil samples. No other metals exceeded all applicable criteria.

4.2.5.5 Cranberry Bog (Reach 2)

Surface soil samples were collected from 10 locations (CB05-01 through CB05-10) off a dirt foot path on the west side of the Cranberry Bog Conservation Area to investigate potential metals contamination deposited by flood waters. The samples were collected by EPA NERL in July 2002 and analyzed for total metals and TOC.

As shown on Table 4-2d, 22 metals were detected in the CB05 samples. Most of the metals were detected in most or all samples. The Region 9 PRGs were exceeded only for arsenic in all 10 samples.

Most metals were detected at concentrations similar to or lower than MADEP background soil criteria. Eleven metals were detected at concentrations exceeding the background criteria. Four of these (arsenic, chromium, cobalt, and zinc) exceeded the criteria in at least half the samples. The remaining metals were detected in four or fewer samples. The maximum concentrations detected for most metals were in the same order of magnitude as the background criteria. Three metals (chromium, selenium, and thallium) had maximum concentrations an order of magnitude greater than the background criteria. Generally, the highest concentrations of metals occurred in the sample from CB05-05.

As shown on Figures 4-2f and 4-2g arsenic exceeded both applicable criteria in 7 of the 10 CBO5 floodplain soil samples. No other metals exceeded all applicable criteria.

4.2.5.6 Danielson Park (Reach 2)

Surface soil samples were collected from five locations (DAP01 through DAP05) along the bank of the Aberjona River, across from Danielson Park, downstream of the Washington Street Bridge in Woburn. The samples were collected by EPA NERL in July 2002 to investigate potential metals contamination deposited by flood waters; the samples were analyzed for total metals and TOC.

As shown on Table 4-2d, 22 metals were detected in the DAP samples. Most of the metals were detected in most or all samples. The Region 9 PRGs were exceeded for arsenic in all 5 samples, and lead and manganese only at DAP03.

Seventeen metals were detected at concentrations exceeding the MADEP background soil criteria. Four metals (arsenic, chromium, copper, and mercury) exceeded background criteria in all five samples from this area and four (cobalt, lead, selenium, and zinc) exceeded background criteria at three or four locations. The remaining nine metals exceeded the criteria at only one or two locations. For eight metals, including arsenic, chromium, copper, mercury, cobalt, and selenium, the maximum concentrations were an order of magnitude higher than the background criteria. For most of these, the average concentrations were also an order of magnitude higher than the background criteria. The maximum concentration of nearly all metals and the largest number of exceedances of background criteria occurred in the sample from DAP03. The sample from DAP05 generally had the next highest concentrations.

As shown on Figures 4-2f and 4-2g arsenic exceeded all applicable criteria at all five DAP floodplain soil locations and lead and manganese exceeded all criteria at only DAP03. No other metals exceeded all applicable criteria.

4.2.5.7 Kraft Foods (Reach 2)

Surface soil samples were collected from 10 locations (KFSO-01 through KFSO-10) along the east bank of the Aberjona River in the Kraft Foods well field to investigate potential metals contamination deposited by flood waters. The samples were collected by EPA NERL in September 2002 and analyzed for total metals and TOC.

As shown on Table 4-2d, 21 metals were detected in the KFSO samples. Most of the metals were detected in most or all samples. The Region 9 PRGs were exceeded only for arsenic in all 10 samples.

Fourteen metals were detected at concentrations exceeding the MADEP background soil criteria and eight of these metals exceeded the criteria in at least eight of ten samples. However, most of the exceedances of background criteria were in the same order of magnitude as the criteria. Only four metals (chromium, cobalt, copper, and manganese) were detected at concentrations an order of magnitude higher than the background criteria; these higher concentrations were detected in the majority of samples only for chromium. The highest concentrations of most metals and the largest number of exceedances of background criteria occurred in the samples from KFSO-05 and KFSO-02.

As shown on Figures 4-2f and 4-2g arsenic exceeded all applicable criteria at 9 of the 10 KFSO floodplain soil locations. No other metals exceeded all applicable criteria.

4.2.5.8 Davidson Park (Reach 3)

Surface soil samples were collected at 26 locations along the east, south, and west sides of the Davidson Park pond (DP01 through DP26) to investigate potential metals contamination deposited by flood waters. These locations were selected to provide representative sample locations with an emphasis on low-lying areas. The samples were collected by TtNUS in July 2000 and analyzed for total metals, pH, redox potential, and sulfide. Five of the samples were also analyzed for hexavalent chromium; it was not detected in any of the samples.

As shown on Table 4-2d, 22 metals were detected in the DP samples. Most of the metals were detected in most or all samples. The Region 9 PRGs were exceeded for arsenic in all 26 samples, and iron and zinc only at DP16.

Eighteen metals were detected at concentrations exceeding the MADEP background soil criteria. Four of these metals (chromium, cobalt, mercury, and zinc) exceeded the background criteria in at least three quarters of the samples. Four more (arsenic, copper, lead, and silver) exceeded criteria in at least half of the samples. Many of the metals exceedances were in the same order of magnitude as the background criteria. However, 11 metals were detected at

concentrations an order of magnitude higher than the background criteria. Seven of these (chromium, cobalt, copper, mercury, selenium, silver, and thallium) were detected at concentrations an order of magnitude higher than the background criteria in several samples. Most of the 26 Davidson Park samples exceeded the MADEP background criteria for several metals. Only three locations had isolated or no exceedances: DP15 (cobalt), DP20 (cobalt and copper), and DP22 (none).

As shown on Figures 4-2h and 4-2i arsenic exceeded all applicable criteria at 13 of the 26 Davidson Park floodplain soil locations. Iron and zinc exceeded all applicable criteria at one location (DP16). No other metals exceeded all applicable criteria.

4.2.5.9 Winchester south of Bacon Street (Reach 5)

Surface soil samples were collected from nine locations (AJRW08 through AJRW24 - even numbers only – samples were collected at AJRW12 and AJRW12R, but only the latter was analyzed) along the south bank of the ponded area of the Aberjona River south of Bacon Street in Winchester to investigate potential metals contamination deposited by flood waters. The samples were collected by EPA NERL in April 2004 and analyzed for total metals.

As shown on Table 4-2d, 16 metals were detected in the AJRW samples. Most of the metals were detected in most or all samples. The Region 9 PRGs were exceeded for arsenic in seven of nine samples, iron in one sample, and lead in two samples.

Fourteen metals were detected at concentrations exceeding the MADEP background soil criteria. Four of these (arsenic, cobalt, lead, and vanadium) exceeded the background criteria in at least three quarters of the samples. Two more (aluminum and chromium) exceeded criteria in five of nine samples. The remaining metals exceeded the criteria in less than half the samples. Most of the exceedances of the MADEP background values were within the same order of magnitude as the criteria. Only the maximum concentrations of barium, copper, magnesium, and mercury, and the three highest cobalt concentrations were an order of magnitude higher than the background criteria. All of the AJRW samples exceeded the background criteria for at least three metals. Stations AJRW10 and AJRW12R had the largest number of metals exceeding background criteria.

As shown on Figures 4-2j and 4-2k arsenic exceeded all applicable criteria at 7 of the 9 AJRW floodplain soil locations. Iron and lead exceeded all applicable criteria at one and two locations, respectively. No other metals exceeded all applicable criteria.

4.3 Groundwater Contamination

As described in Section 2, several groundwater investigations were conducted by the ISRT and TtNUS between 1990 and 2002 to evaluate area-wide groundwater contamination in the Northern Study Area. The field investigations conducted by the ISRT under the GSIP (1990 – 2002) focused on groundwater at and immediately downgradient from the Industri-plex Site. The field investigations conducted by TtNUS under the MSGRP (2001 – 2002) supplemented the GSIP investigations in the vicinity of the site, and also included the collection of groundwater samples from outside the immediate area of the Industri-plex Site to evaluate other potential sources of groundwater contamination in the area.

The quantitative evaluation of the nature and extent of contamination presented in this section focuses on the most recent data, collected during the final phase of GSIP investigations (2000 – 2002) and the MSGRP investigation. These data are considered to be most representative of the current conditions in the study area aquifer. In addition, nine locations (A01, A02, A03, A04, A05, A06, A07, A022, and A023) sampled by EPA ORD in 1999-2000 for the Industri-plex Site Natural Attenuation Study (Ford, 2004a) (included in Appendix 2D) were included to help define the extent of contamination in the vicinity of South Pond and the West Hide Pile. Data from earlier investigations (pre-1999) are considered qualitatively to supplement and provide a temporal perspective on the recent data. Complete analytical data from the 2000 through 2002 GSIP and MSGRP investigations are presented in Appendix 4B. Analytical data from the Natural Attenuation Study are included in Appendix 2D

The evaluation of the nature and extent of groundwater contamination is divided into two groups based on the applicable groundwater quality criteria. The entire Northern Study Area is evaluated first; then the Northern Study Area wells closest to the southern border of the study area are evaluated separately. The evaluation criteria for each group are described in the following section.

4.3.1 Groundwater Comparison Criteria

Appropriate reference criteria for the Northern Study Area groundwater were determined based on the MADEP “Groundwater Use and Value Determination” for the Industri-plex Site (MADEP, 1997), described in Section 3.2.2.4 and the MCP. The “Groundwater Use and Value Determination” identified the applicable MCP Groundwater Classifications and MCP Method 1 Groundwater Quality Standards for the Northern Study Area.

Northern Study Area – As discussed in Section 3.2.2.4, the aquifer in the Northern Study Area is a NPDWSA with GW-2 and GW-3 groundwater classifications. Therefore, groundwater throughout the Northern Study Area must meet GW-3 standards (MCP Method 1). In areas where there is a potential for the migration of vapors from groundwater into occupied structures, it must also meet GW-2 standards (MCP Method 1). To simplify the evaluation and identify any areas that may pose a threat to human health or the environment, samples from throughout the area were evaluated relative to both the GW-2 and GW-3 standards.

Northern Study Area - Southern Perimeter Wells – As discussed in Section 3.2.2.4, the southern boundary of the Northern Study Area borders the IWPA for municipal wells G and H; consequently, groundwater leaving the Northern Study Area and entering the IWPA must meet GW-1 standards. Although the southernmost wells in the study area (the AF and P series wells) are approximately 150 to 450 feet north of the IWPA and within the GW-2/GW-3 area, groundwater from these wells were evaluated relative to the GW-1 standards to determine whether the groundwater leaving the study area meets the GW-1 criteria.

4.3.2 Northern Study Area Groundwater

The discussion of the nature and extent of groundwater contamination in the Northern Study Area is limited to contaminants that exceeded an applicable water quality standard in at least one groundwater sample collected during the MSGRP and final GSIP investigations. Additionally, plume maps were developed for arsenic, zinc benzene, toluene, and trichloroethene because they were identified as contaminants of greatest concern.

Groundwater Data Set – The Northern Study Area evaluation is based on chemical analytical results from 534 sample locations (198 boring locations with 1 to 11 samples collected at

different depths within each boring). Groundwater samples were collected using low-flow methods, and most samples were not filtered. Filtered data was only used for metals and SVOCs when groundwater monitoring parameters (usually turbidity) did not stabilize during sampling. Summary statistics for measured chemical constituents are presented in Tables 4.3a (study area metals) and 4.3b (study area organics).

Plume Maps – The spatial distributions of arsenic, zinc benzene, toluene, and trichloroethene were modeled using Visual Groundwater™ Version 2.2. This software package uses both the spatial coordinates and the chemical analytical data for each monitoring point to: 1) contour contaminant concentrations in three dimensions and 2) produce two-dimensional images of the distribution of contaminants throughout the study area. Figures 4-3a through 4-3e present the plume maps produced by Visual Groundwater™. Each figure includes several plan views and a cross-sectional view positioned through locations of high concentrations. The plan views reveal the distribution of contamination at different elevations in the aquifer. The cross section helps delineate the geometries of high-concentration areas and the variability in contaminant concentrations with depth.

The patterns of contamination shown in Figures 4-3a through 4-3e are generally compatible with the patterns that would be predicted from both the source information presented in Section 4.1 and the groundwater flow directions depicted on Figures 3-5 through 3-7. This compatibility supports the assertion that the images approximate the actual distribution of groundwater contamination within the study area. The groundwater data used in the modeling is presented in Appendix 4B-2. A further discussion of the plume imaging process, including its strengths and limitations, is included in Appendix 4B-3.

4.3.2.1 Metals Contamination - Northern Study Area Groundwater

Seven metals (arsenic, cadmium, chromium, lead, mercury, nickel, and zinc) exceeded GW-2/GW-3 standards in one or more groundwater samples (Table 4.3a). Arsenic was detected in 360 out of 467 samples. Forty-four of the samples (12 percent) exceeded the arsenic GW-3 criterion of 400 µg/L, and the highest concentration (24,400 µg/L) was observed at B7-01. Figure 4-3a shows that arsenic concentrations were highest in the groundwater south and west of the East Central Hide pile and beneath the Boston Edison Company Easement.

Cadmium was found in 34 of 191 groundwater samples, and three samples exceeded the GW-3 criterion of 10 µg/L. The highest concentration of cadmium (19.9 µg/L) was detected in the shallow groundwater at AP03, about 100 feet north of the East Central Hide pile. Although chromium was detected in 177 samples, only two samples exceeded the GW-3 standard of 2000 µg/L, and both samples were collected from B6-04, located approximately 450 feet south of Atlantic Avenue.

Groundwater from 49 samples contained detectable levels of lead, and 23 surpassed the GW-3 criterion of 30 µg/L. The highest concentration of lead (2640 µg/L) was found beneath the Boston Edison Company Easement at B7-01. All locations where lead was found at concentrations above 100 µg/L were restricted to an area north of the Halls Brook Holding Area pond, east of New Boston Road, and west of Atlantic Avenue.

Concentrations of mercury topped the GW-3 standard of 1 µg/L in 8 of the 19 samples in which it was detected. As with arsenic and lead, the highest concentration of mercury (15.9 µg/L) was found at B7-01. The second and fourth highest concentrations (5.2 and 1.9 µg/L) were also detected at B7-01, but at different depths. The other five locations where mercury was found above 1 µg/L were distributed across the study area.

The GW-3 criteria for nickel and zinc (80 and 900 µg/L, respectively) were also exceeded in isolated areas extending from the AP locations south of the East Hide Pile to P1-01 south of Mishawum Road. The criterion for nickel was surpassed at five locations with the highest concentration (114 µg/L) at AP-02. The criterion for zinc was exceeded at 11 locations, and the two highest concentrations were observed at B4-04, about 600 feet west of the western end of Atlantic Avenue. Figure 4-3b shows the distribution of zinc in groundwater.

4.3.2.2 SVOCs - Northern Study Area Groundwater

Only one semivolatile organic compound exceeded a GW-2 or GW-3 standard in the Northern Study Area. Pentachlorophenol was detected in two groundwater samples: one at B1-04 in the East Central Hide Pile, and the other at W5-5 along the southern edge of the Boston Edison Company Easement. The concentration at B1-04 (150 µg/L) exceeded the GW-03 criterion of 80 µg/L.

4.3.2.3 VOCs - Northern Study Area Groundwater

Two volatile organic compounds, 1,1-dichloroethene and benzene, exceeded a GW-2 or GW-3 standard in the Northern Study Area. 1,1-Dichloroethene was detected in 12 samples, six samples had concentrations above the GW-2 criterion of 1 µg/L, and the highest concentration (8.4 µg/L) was found at AE03. All of the samples that surpassed the GW-2 standard were located south and southwest of Cabot Road in the vicinity of former Mishawum Lake.

Benzene was found in 60 samples, 18 exceeded the GW-02 standard of 2000 µg/L, and eight topped the GW-03 standard of 7000 µg/L. The maximum concentration (69,000 µg/L) was observed in the shallow groundwater at RX-17, about 150 feet east of the western end of Atlantic Avenue. In the shallow groundwater, the highest concentrations of benzene were observed in two areas: between the East Central and South hide piles, and along the eastern edge of the West Hide Pile. In the deeper groundwater, high concentrations of benzene extended from the south side of Atlantic Avenue to the southern end of the Halls Brook Holding Area Pond (see Figure 4-3c).

Two additional VOCs (toluene and trichloroethene) were evaluated and mapped even though they did not exceed a GW-2 or GW-3 standard. Figures 4-3d and 4-3e show the spatial distributions of toluene and trichloroethene in groundwater. High concentrations of toluene (up to 2500 µg/L) occur in two areas: at intermediate depths between the East Central and South hide piles, and in the intermediate and deeper overburden beneath and immediately south of the Boston Edison Company Easement. The spatial distribution of toluene is similar to that of benzene, except that high concentrations of toluene are not found in the shallow groundwater near the West Hide Pile.

Trichloroethene is observed in two portions of the study area. It is found at low concentrations (less than 6 µg/L) in the shallow groundwater surrounding North Pond, and it is present at higher concentrations (up to 110 µg/L) in the intermediate to deep overburden extending from the Boston Edison Company Easement to Mishawum Road (see Figure 4-3e). The highest concentration was detected in the deep overburden at AE03.

4.3.3 Southern Perimeter Groundwater

Chemical analytical data for samples collected from the Northern Study Area wells that were positioned along the southern border of the study area were evaluated and compared to MCP GW-1 standards. Data from the AF and P series wells were assessed to determine whether or not the groundwater leaving the study area meets GW-1 drinking water standards before entering the IWPA of Wells G&H.

Groundwater Data Set – The southern boundary evaluation is based on analytical results from 57 sample locations (10 boring locations with 1 to 11 samples collected at different depths within each boring). Groundwater samples were collected using low-flow methods, and most samples were not filtered. Filtered data was only used for metals and SVOCs when groundwater monitoring parameters (usually turbidity) did not stabilize during sampling. Summary statistics for measured chemical constituents are presented in Tables 4-3c (southern perimeter metals) and 4-3d (southern perimeter organics)

4.3.3.1 Metals Contamination – Southern Perimeter Groundwater

Arsenic, cadmium, lead, nickel, thallium, and zinc exceeded GW-1 standards in at least one groundwater sample collected from the AF and P series wells. Three samples exceeded the GW-1 standard of 50 µg/L for arsenic, and the highest concentration (92.4 µg/L) was found 15 feet below the water table at P1-02. Only one sample surpassed the GW-1 standard of 5 µg/L for cadmium; the sample was collected approximately 33 feet below the water table at P1-03 and contained 6.9 µg/L of cadmium. This sample also contained the maximum detected concentration of lead (87.6 µg/L). Three additional samples had lead concentrations above the GW-1 criterion of 15 µg/L. Only one sample, collected from the deep overburden at P1-01, topped the GW-1 criterion for nickel (100 µg/L) or zinc (2000 µg/L); it contained 111 µg/L of nickel and 3000 µg/L of zinc. Thallium exceeded the GW-1 criterion of 2 µg/L in both of the samples in which it was detected. The highest concentration of thallium (13.7 µg/L) was found 24 ft below the water table at P1-04.

4.3.3.2 SVOCs – Southern Perimeter Groundwater

Bis(2-ethylhexyl)phthalate was the only SVOC that exceeded its GW-1 criterion in a southern perimeter well. Concentrations were above the 6 µg/L standard in both of the samples in which it was found. The highest concentration (15 µg/L) was observed in the groundwater 35 ft below the water table at P1-04.

4.3.3.3 VOCs – Southern Perimeter Groundwater

Only one VOC exceeded its GW-1 criterion in a southern perimeter well. Methyl tert-butyl ether (MTBE) surpassed the 70 µg/L standard in one of the seven samples in which it was detected. The shallow groundwater sample from AF02 contained 4000 µg/L of MBTE.

4.3.4 **Comparisons with Earlier (pre-1999) Results**

Section 4.3.4 presents a qualitative evaluation of changes in the benzene and toluene plumes between the years 1983 and 2002. The evaluation is based on a visual comparison of the plume images presented in Roux's "Historical Benzene/Toluene Concentrations Industri-plex Site" figure (see Appendix 4B-4) with those shown in Figures 4-3c and 4-3d. A more rigorous assessment of temporal changes in plume geometry or mass is not possible, because the number of samples and the locations of samples differ between the datasets, and the pre-1999 data were interpolated in two, rather than three dimensions. In addition, the earlier groundwater samples were collected with bailers, while the Phase 3 GSIP and MSGRP samples were collected using low flow methodology. Changes in the arsenic, zinc, and trichloroethene plumes could not be evaluated, because the pre-1999 investigation reports did not contain plume maps for these three contaminants.

The Roux figure in Appendix 4B-4 contains a sequence of four benzene plume maps that were created from groundwater data collected in 1983, 1989-1992, 1993, and 1997. All four plume maps show a northeast-southwest trending benzene plume positioned between Atlantic Avenue and the Halls Brook Holding Area Pond. Although the mass and lateral extent of benzene in groundwater appear to decrease between 1983 and 1997, the number of samples and the locations of samples differ between the four datasets, so conclusions regarding temporal changes in benzene mass and plume geometry cannot be drawn from these images. Figure 4-

3c shows that benzene concentrations remain high in the area between Atlantic Avenue and the Halls Brook Holding Area Pond (up to 21,000 µg/L at RX-6). However, the highest concentration of benzene (69,000 µg/L) was detected immediately north of Atlantic Avenue, and as much as 4000 µg/L were observed in the shallow groundwater along the eastern edge of the West Hide Pile, roughly 1800 ft north of Atlantic Avenue.

The Roux figure also contains a series of toluene plume maps for 1983, 1989-1992, 1993, and 1997. Again, the extent of contamination appears to decrease between 1983 and 1997, but the number of samples and the locations of samples differ between the four datasets. The four plume maps indicate that toluene contamination is restricted to the area between the East Central Hide Pile and the Halls Brook Holding Area Pond. Figure 4-3d shows that high concentrations of toluene (up to 3600 µg/L) are still limited to this area.

4.4 Sediment Contamination

As described in Section 2, several investigations have been conducted by the ISRT, EPA, FW, M&E, and TtNUS to determine the nature and extent of contamination present in study area sediment. This section presents the evaluation of analytical data collected during those investigations. The evaluation of the nature and extent of sediment contamination is divided into two groups according to sample types and sampling rationale: surface sediment samples and sediment core samples. The nature and extent of sediment contamination in the study area are evaluated in relation to the comparison criteria identified in Section 4.4.1 to assess whether contaminant concentrations detected in site media are elevated relative to reference values.

4.4.1 Sediment Comparison Criteria

To assess whether contaminant concentrations detected in site media are elevated and may pose a potential threat, it is necessary to compare the concentrations detected in samples collected from the site to appropriate reference concentrations. For Study Area sediments, three sets of reference values were used as indicators of potential threats to human health and the environment and to evaluate whether concentrations are elevated relative to natural background conditions:

- EPA Region 9 Preliminary Remediation Goals (PRGs) for Residential Soil (USEPA, 2004) – The Region 9 PRGs are concentrations of potential human health concern developed by EPA Region 9 for nearly 600 chemicals in various media. The PRGs are widely used as screening criteria to identify contamination that may be harmful to people. The criteria for soils are used as a surrogate for sediment-specific criteria because Region 9 PRGs have not been developed specifically for sediment. The PRGs are calculated based on a risk level of 1×10^{-6} for potential carcinogens or a hazard quotient (HQ) of 1 for noncarcinogens, using reasonable maximum residential exposure assumptions for soil. The PRG for lead is set at the residential soil screening level of 400 mg/kg (USEPA, 1994); the PRG for chromium III is used for chromium; the PRG for methylmercury is used for mercury; and the most conservative PRG of all non-carcinogenic PAHs (naphthalene) is used for acenaphthalene, benzo(g,h,i)perylene; and phenanthrene.
- Ontario Ministry of the Environment and Energy (OMEE) Severe-Effects Level (SEL) sediment quality guidelines (Persaud, 1993) – The OMEE SELs are sediment contaminant concentrations of potential concern to benthic organisms developed for 43 metals, SVOCs, pesticides, and PCBs. The SELs are concentrations at which detrimental effects would be expected for the majority of benthic species in the sediment. The SELs were derived from 90th and 95th percentile screening level concentrations (SLC), which represent the level of contamination that can be tolerated by 10 percent and 5 percent of the benthic infaunal species, respectively. Most of the SELs were derived from 95th percentile SLC; the SELs for PCBs and the pesticides alpha-BHC, gamma-BHC, and heptachlor epoxide were derived from 90th percentile SLC.
- Study area background concentrations for surface sediment – Surface sediment samples were collected from 27 local and regional reference stations that were judged to be representative of background conditions. The reference stations were located in areas representative of study area habitats, but not likely to be impacted by site- or other-contaminant sources. They are located in areas outside the main basin of the Aberjona River or upgradient of the influence of the Wells G&H and Industri-plex Sites, in areas unlikely to be significantly impacted by other sources of contamination. Sediment reference stations are shown on Figures 2-7I and 2-7J. The average concentrations detected in the reference data set were used as comparison

concentrations for evaluating sediment contamination within the study area. The average concentrations for the reference data set were calculated using the detected values and one-half the detection limit for non-detected values. In some cases, where detection limits are higher than the detected concentrations, the calculated average concentration may be higher than the maximum detected concentration, but within the range of detection limits. The reference data are evaluated in Section 4.4.2, along with the surface sediment data for the study area.

The analytical data for samples in each area were compared to the reference criteria to identify areas of contamination that may pose a threat to human health or the environment. The narrative and tables presented in Sections 4.4.2 and 4.4.3 identify exceedances of the individual criteria. In order to identify the areas with the highest level of contamination, which may pose the greatest threats to humans health and the environment, the accompanying figures highlight the sample locations where detected contaminants exceed all available criteria, including at least one criterion established for protection of human health or the environment (Region 9 PRG or OMEE SEL). This eliminates analytes that exceed only the average background concentrations, but includes analytes for which a PRG or an SEL have not been developed.

4.4.2 Surface Sediment

Surface sediments samples were collected from river, lake, and wetland locations throughout the RI study area during several GSIP and MSGRP investigations from 1995 through 2004. The samples were collected to determine the nature and extent of contaminants present in study area sediments and to support study area human health and ecological risk assessments. The surface sediment samples were collected from the 0- to 6-inch sediment depth interval. All sediment samples were analyzed for metals, some were also analyzed for VOCs, SVOCs, pesticides, and PCBs. See Sections 2.1.5.5, 2.2.1.1, 2.2.1.2, 2.2.2.1, and 2.2.3.1 and Tables 2-4 and 2-5 for additional investigation details. Sediment sample locations are shown on Figures 2-7a through 2-7j.

The analytical results are discussed in the sections below. The discussion is organized by analyte group and within each group, by segment of the study area. The study area segments or “reaches” were defined based on the characteristics each area, as discussed in Section 2.2.1. Summary statistics and comparisons to reference concentrations for each study

area segment are presented in Tables 4-4a through 4-4c. Complete analytical data for sediment are presented in Appendix 4C. Sample locations where contaminant concentrations exceed all applicable reference criteria are shown on Figures 4-4a through 4-4w.

4.4.2.1 Metals – Surface Sediment

The nature and extent of metals detected in surface sediment are discussed below. The results for the study area reference (background) stations data set are presented first, followed by the results for each study area reach, from north to south (upstream to downstream).

Reference Stations Surface Sediment – Metals

Surface sediment samples were collected from 27 local and regional reference located in areas representative of study area habitats, but not likely to be impacted by site- or other-contaminant sources. The reference stations are located in areas outside the main basin of the Aberjona River or upgradient of the influence of the Wells G&H and Industri-plex Sites. Sediment reference stations are shown on Figures 2-7I and 2-7J. All reference station samples were analyzed for metals. Reference data summary statistics and comparisons to reference criteria are presented in Table 4-4a. Complete analytical results are presented in Appendix 4C.

As shown on Table 4-4a, 23 metals were detected in reference station surface sediments. Most of the metals were detected in all or most samples; only three metals were detected in fewer than 50 percent of samples.

The EPA Region 9 PRGs for residential soil were exceeded for five metals in the reference station sediment (arsenic, iron, lead, manganese, and vanadium). Arsenic exceeded the PRG in all 27 samples, with all concentrations exceeding the PRG by one or two orders of magnitude. The other four metals exceeded the PRGs in fewer than one fourth of the samples. For each of these metals except vanadium, the maximum concentration was in the same order of magnitude as the Region 9 PRG and the average concentration was below the criteria. For vanadium, the maximum concentration exceeded the PRG by one order of magnitude, but all other samples had similar or lower concentrations.

As shown on Table 4-4a, the OMEE SELs were exceeded for six metals in reference station sediment (arsenic, chromium, copper, iron, lead, and manganese). Each of these metals exceeded the criteria in fewer than one third of the samples. For all six metals, the maximum concentration was in the same order of magnitude as the SELs and the average concentration was below the criteria.

Summary of Study Area – Surface Sediment Metals

A total of 429 surface sediment samples were collected from throughout the RI study area and analyzed for metals. Approximately 75 percent of the samples were collected from Reaches 0, 1, and 2, with the remaining samples distributed among sediment deposition areas in the rest of the river and the Mystic Lakes. The highest concentrations of metals and the most exceedances of reference criteria were found in the Halls Brook Holding Area (Reach 0), the Wells G&H wetlands (Reach 1), and the Cranberry Bog Conservation Area (Reach 2 North). The concentrations and frequency of criteria exceedances were generally highest in the HBHA, decreased somewhat in Reaches 1 and 2, decreased further in Reaches 3, 4, and 5, and then increased again in Reach 6. The number of metals exceeding reference criteria was highest in Reach 1, followed by Reaches 2 and 0.

Additional details of the nature and extent of metals contamination in individual study area reaches are provided in the sections below. Summary statistics and comparisons to reference criteria for metals in surface sediment are presented in Table 4-4b. Complete analytical results are presented in Appendix 4C. Sample locations where metals concentrations exceeded all applicable reference criteria are shown on Figures 4-4a through 4-4o.

Reach 0 Surface Sediment – Metals

Surface sediment samples were collected from 78 sample stations in Reach 0 and analyzed for metals. Most of the samples (51) were collected from the HBHA pond and wetland, fewer were collected from the Aberjona River before the confluence at Mishawum Road (6), the East Drainage Ditch (11) and the drainage channels in the BECO ROW (10). Summary statistics and comparisons to reference criteria are presented in Table 4-4b. Sample locations in Reach 0 where metals concentrations exceed all applicable reference criteria are presented on Figures 4-4a and 4-4b.

As shown on Table 4-4b, 24 metals were detected in Reach 0 surface sediments. All of the metals were detected in most or all samples. The highest metals concentrations were generally detected in the HBHA samples. Samples from 7 of the 78 stations were analyzed for hexavalent chromium; it was detected at low concentrations (less than 1 mg/kg) in 6 of the 7 samples.

The EPA Region 9 PRGs for residential soil were exceeded for seven metals (arsenic, cadmium, iron, lead, manganese, thallium, and vanadium) in the Reach 0 sediment. Arsenic exceeded the PRG in all 78 samples, with concentrations exceeding the PRG by one to five orders of magnitude. Iron exceeded the PRG in more than half the samples, with the average concentration of all samples also exceeding the PRG. The remaining metals all exceeded the PRGs in fewer than one fourth of the samples. For each of these five metals except thallium, the maximum concentration was in the same order of magnitude as the Region 9 PRG. For thallium, three samples had concentrations that exceeded the PRG by one order of magnitude, but all other samples had similar or lower concentrations.

As shown on Table 4-4b, the OMEE SELs were exceeded for nine metals (arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, and zinc) in Reach 0 sediment samples. Four of these (arsenic, chromium, copper and zinc) exceeded the criteria in more than half the samples. For most of these metals, the maximum concentration was within one order of magnitude higher than the SEL and the average concentration of all samples in the reach was in the same order of magnitude or below the criteria. Only arsenic and zinc were detected at concentrations more than an order of magnitude above their SELs and the average concentration for these metals exceeded the SEL by an order of magnitude.

As shown on Table 4-4b, all metals detected in Reach 0 were present at concentrations above their study area average background concentrations. Most of the metals exceeded the background concentrations in more than half the samples in the reach.

Seven metals (arsenic, cadmium, iron, lead, manganese, thallium, and vanadium) exceeded all applicable criteria in sediment from at least one sample location in Reach 0. Figures 4-4a and 4-4b show the sample locations where all applicable criteria were exceeded for individual metals. As illustrated on Figure 4-4a, arsenic exceeded all applicable criteria at nearly every location. As shown on Figure 4-4b, approximately half of the sample locations in Reach 0 also

exceeded all applicable criteria for at least one additional metal. Iron was the most prevalent of the other metals exceeding all criteria.

Reach 1 Surface Sediment – Metals

Surface sediment samples were collected from 147 sample stations in Reach 1 and analyzed for metals. Most of the samples were collected from within the Wells G&H wetland. A few samples were also collected from the wetland area north of Olympia Avenue, off Normac Road. Summary statistics and comparisons to reference criteria are presented in Table 4-4b. Sample locations in Reach 1 where metals concentrations exceed all applicable reference criteria are presented on Figures 4-4c and 4-4d.

As shown on Table 4-4b, 25 metals were detected in Reach 1 surface sediments. Most of the metals were detected in most or all samples. Samples from 15 of the 147 stations were analyzed for hexavalent chromium; it was detected in only one sample.

The EPA Region 9 PRGs for residential soil were exceeded for nine metals in Reach 1: the seven metals that exceeded PRGs in Reach 0 (arsenic, cadmium, iron, lead, manganese, thallium, vanadium), plus antimony, and mercury. Arsenic exceeded the PRG nearly every sample, with concentrations exceeding the PRG by one to four orders of magnitude. Iron and lead exceeded the PRGs in 44 percent and 53 percent of the samples, respectively, with their average concentrations also exceeding the PRGs. The remaining metals all exceeded the PRGs in fewer than one fourth of the samples. For each of these metals the maximum concentration was within one order of magnitude of the Region 9 PRG.

As shown on Table 4-4b, the OMEE SELs were exceeded for 10 metals in Reach 1: the same nine that exceeded SELs in Reach 0 (arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, and zinc), plus nickel. Five of these (arsenic, chromium, copper, lead, and zinc) exceeded the criteria in more than half the samples. For most of these metals, the maximum concentration was within one order of magnitude higher than the SEL and the average concentration of all samples in the reach was in the same order of magnitude or below the criteria. Only arsenic, chromium, and lead were detected at concentrations more than an order of magnitude above their SELs. The average concentrations of arsenic and chromium were an order of magnitude higher than the SEL.

As shown on Table 4-4b, all metals detected in Reach 1 were present at concentrations above their study area average background concentrations. Most of the metals exceeded the background concentrations in more than half the samples in the reach.

Nine metals (arsenic, cadmium, iron, lead, manganese, thallium, vanadium, antimony, and mercury) exceeded all applicable criteria in sediment from at least one sample location in Reach 1. Figures 4-4c and 4-4d show sample locations in Reach 1 where all applicable criteria were exceeded. As illustrated on Figure 4-4c, arsenic exceeded all applicable criteria at approximately three quarters of the sample locations. The locations that did not exceed all criteria for arsenic were generally on the outer edges of the wetland, far from stream channels. As shown on Figure 4-4d, more than half of the sample locations in Reach 1 also exceeded all applicable criteria for at least one additional metal. Lead was the most prevalent of the other metals exceeding all criteria, followed by iron.

Reach 2 North Surface Sediment – Metals

Surface sediment samples were collected from 89 sample stations in Reach 2 North (2N) and analyzed for metals. The Cranberry Bog Conservation Area (CBCA) constitutes most of the area in this reach. The sediment samples were collected from the main channel of the Aberjona River and from drainage channels within the wetlands of the former bog. Summary statistics and comparisons to reference criteria are presented in Table 4-4b. Sample locations in Reach 2N where metals concentrations exceed all applicable reference criteria are presented on Figures 4-4e and 4-4f.

As shown on Table 4-4b, 24 metals were detected in Reach 2N surface sediments. Most of the metals were detected in most or all samples. Samples from three stations in Reach 2N were analyzed for hexavalent chromium; it was not detected in any of the samples.

The EPA Region 9 PRGs for residential soil were exceeded for eight metals in Reach 2N (arsenic, iron, lead, manganese, thallium, vanadium, mercury, and copper). Arsenic exceeded the PRG every sample, with concentrations exceeding the PRG by one to four orders of magnitude. Iron exceeded the PRGs in approximately one quarter of the Reach 2N samples, with the maximum concentration in the same order of magnitude as the PRG. The remaining

metals all exceeded the PRGs in fewer than 15 percent of the samples. For each of these metals the maximum concentration was within one order of magnitude of the Region 9 PRG.

As shown on Table 4-4b, the OMEE SELs were exceeded for 10 metals in Reach 2N, the same metals that exceeded SELs in Reach 1 (arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, zinc, and nickel). Arsenic, chromium, and copper exceeded the criteria in more than half the samples in Reach 2 North. The remaining metals exceeded the criteria in less than a third of the samples. Arsenic was detected at concentrations two orders of magnitude above its SEL. All the other metals were detected at concentrations within one order of magnitude higher than the SELs.

As shown on Table 4-4b, all metals detected in Reach 2N were present at concentrations above their study area average background concentrations. Most of the metals exceeded the background concentrations in less than half the samples in the Reach 2N.

Eight metals (arsenic, iron, lead, manganese, thallium, vanadium, mercury, and copper) exceeded all applicable criteria in sediment from at least one sample location in Reach 2N. Figures 4-a and 4-b show sample locations in Reach 2N where all applicable criteria were exceeded. As illustrated on Figure 4-4e arsenic exceeded all applicable criteria at more than half of the sample locations in Reach 2N; exceedances occurred in wetland and stream channel locations throughout the CBCA. As shown on Figure 4-4f, approximately one quarter of the sample locations in Reach 2N exceeded all applicable criteria for at least one additional metal. Iron and lead were the most prevalent of the other metals exceeding all criteria.

Reach 2 South Surface Sediment – Metals

Surface sediment samples were collected from 14 sample stations in Reach 2 South (2S) and analyzed for metals. Summary statistics and comparisons to reference criteria are presented in Table 4-4b. Sample locations in Reach 2S where metals concentrations exceed all applicable reference criteria are presented on Figure 4-4g.

As shown on Table 4-4b, 24 metals were detected in Reach 2S surface sediments. Most of the metals were detected in most or all samples. One sample from Reach 2S was analyzed for hexavalent chromium; it was not detected.

The EPA Region 9 PRGs for residential soil were exceeded for two metals in Reach 2S (arsenic, and iron). Arsenic exceeded the PRG every sample, with concentrations exceeding the PRG by two to four orders of magnitude. Iron exceeded the PRGs in 2 of 14 samples, with the maximum concentration in the same order of magnitude as the PRG.

As shown on Table 4-4b, the OMEE SELs were exceeded for five metals in Reach 2S (arsenic, chromium, copper, manganese, and zinc). Arsenic exceeded the criteria in half of the samples; the remaining metals in one to four of the 14 samples. The maximum concentrations of all five metals were in the same order of magnitude as the SELs.

As shown on Table 4-4b, most metals detected in Reach 2S were present at concentrations above their study area average background concentrations. Most of the metals exceeded the background concentrations in only a few samples – only four exceeded background concentrations in more than half of the samples.

Only arsenic exceeded all applicable criteria in sediment from at least one sample location in Reach 2S. As shown on Figure 4-4g arsenic exceeded all applicable criteria at half of the sample locations in Reach 2S, primarily in the stream channel adjacent to the Kraft Foods well field (KFSD samples).

Reach 3 Surface Sediment – Metals

Surface sediment samples were collected from 30 sample stations in Reach 3 and analyzed for metals. Most of the samples were collected from depositional areas around Davidson Park and Leonard Pool. Summary statistics and comparisons to reference criteria are presented in Table 4-4b. Sample locations in Reach 3 where metals concentrations exceed all applicable reference criteria are presented on Figures 4-4h and 4-4i.

As shown on Table 4-4b, 24 metals were detected in Reach 3 surface sediments. Most of the metals were detected in most or all samples. Samples from two stations were analyzed for hexavalent chromium; it was not detected in either sample.

The EPA Region 9 PRGs for residential soil were exceeded for four metals in Reach 3 (arsenic, iron, lead, and vanadium). Arsenic exceeded the PRG in every sample, with concentrations

exceeding the PRG by one to three orders of magnitude. The other three metals exceeded the PRGs in fewer than 30 percent of the samples. For each of these metals the maximum concentration was in the same order of magnitude as the Region 9 PRG.

As shown on Table 4-4b, the OMEE SELs were exceeded for seven metals in Reach 3 (arsenic, cadmium, chromium, copper, lead, mercury, and zinc). Only arsenic and copper exceeded the criteria in more than half the samples. For all seven metals, the maximum detected concentration was within one order of magnitude higher than the SEL and the average concentration of all samples in the reach was in the same order of magnitude or below the criteria.

As shown on Table 4-4b, all metals detected in Reach 3 were present at concentrations above their study area average background concentrations. Most of the metals exceeded the background concentrations in less than half the samples in the reach.

Three metals (arsenic, lead, and vanadium) exceeded all applicable criteria in sediment from at least one sample location in Reach 3. Figures 4-4h and 4-4i show sample locations in Reach 3 where all applicable criteria were exceeded. As illustrated on these figures, arsenic exceeded all applicable criteria at approximately half of the sample locations, lead exceeded applicable criteria at five of those locations, and vanadium exceeded applicable criteria at one of those locations. Arsenic exceedances occurred in each of the deposition areas sampled.

Reach 4 Surface Sediment – Metals

Surface sediment samples were collected from eight sample stations in Reach 4 and analyzed for metals. Most of the samples were collected from Judkins Pond; two were collected from Mill Pond. Summary statistics and comparisons to reference criteria are presented in Table 4-4b. Sample locations in Reach 4 where metals concentrations exceed all applicable reference criteria are presented on Figures 4-4j and 4-4k.

As shown on Table 4-4b, 24 metals were detected in Reach 4 surface sediments. Most of the metals were detected in most or all samples. Samples from three stations were analyzed for hexavalent chromium; it was not detected in any of the samples.

The EPA Region 9 PRGs for residential soil were exceeded for three metals in Reach 4 (arsenic, iron, and lead). Arsenic exceeded the PRG in every sample, with concentrations exceeding the PRG by two to three orders of magnitude. Iron and lead each exceeded the criteria in only two samples. In both cases, the maximum concentration was in the same order of magnitude as the Region 9 PRG.

As shown on Table 4-4b, the OMEE SELs were exceeded for eight metals in Reach 4 (arsenic, chromium, copper, iron, lead, manganese, mercury, and zinc). Five of these metals (arsenic, chromium, copper, lead, and zinc) exceeded the criteria in more than half the samples. For all eight metals, the maximum detected concentration was in the same or one order of magnitude higher than the SEL. Average concentrations for all metals except zinc were similar to or lower than the SEL.

As shown on Table 4-4b, all metals detected in Reach 4 were present at concentrations above their study area average background concentrations. Most of the metals exceeded the background concentrations in at least half of the samples in the reach.

Three metals (arsenic, iron, and lead) exceeded all applicable criteria in sediment from at least one sample location in Reach 4. Figures 4-4j and 4-4k show sample locations in Reach 4 where all applicable criteria were exceeded. As illustrated on these figures, arsenic exceeded all applicable criteria at six of the eight surface sediment sample locations, lead exceeded applicable criteria at two of those locations and iron exceeded applicable criteria at one of those locations.

Reach 5 Surface Sediment – Metals

Surface sediment samples were collected from 19 sample stations in Reach 5 and analyzed for metals. Most of the samples were collected from the ponded area of the Aberjona River between Bacon Street and the Upper Mystic Lake in Winchester. Summary statistics and comparisons to reference criteria are presented in Table 4-4b. Sample locations in Reach 5 where metals concentrations exceed all applicable reference criteria are presented on Figures 4-4l and 4-4m.

As shown on Table 4-4b, 22 metals were detected in Reach 5 surface sediments. Most of the metals were detected in most or all samples. No samples from Reach 5 were analyzed for hexavalent chromium.

The EPA Region 9 PRGs for residential soil were exceeded for three metals in Reach 5 (arsenic, iron, and lead). Arsenic exceeded the PRG in 11 of 18 samples, with concentrations exceeding the PRG by two to two orders of magnitude. Iron and lead exceeded the criteria in one and four samples, respectively. The maximum concentration of iron was in the same order of magnitude as the Region 9 PRG. The maximum concentration of lead exceeded the PRG by an order of magnitude.

As shown on Table 4-4b, the OMEE SELs were exceeded for four metals in Reach 5 (arsenic, chromium, copper, and lead). None of these metals exceeded the criteria in more than half of the samples. For all four metals, the maximum detected concentration was in the same or one order of magnitude higher than the SEL. Average concentrations for all metals were similar to or lower than the SEL.

As shown on Table 4-4b, all metals except silver detected in Reach 5 were present at concentrations above their study area average background concentrations. Most of the metals exceeded the background concentrations in less than half of the samples in the reach.

Only arsenic and lead exceeded all applicable criteria in sediment from at least one sample location in Reach 5. Figures 4-4l and 4-4m show sample locations in Reach 5 where all applicable criteria were exceeded. As illustrated on these figures, arsenic exceeded all applicable criteria at 3 of the 19 sediment sample locations and lead exceeded applicable criteria at four sample locations. Only one of the locations (AJRW-03) had exceedances of both metals.

Reach 6 Surface Sediment – Metals

Surface sediment samples were collected from 44 sample stations in Reach 6 and analyzed for metals. Summary statistics and comparisons to reference criteria are presented in Table 4-4b. Sample locations in Reach 6 where metals concentrations exceed all applicable reference criteria are presented on Figures 4-4n and 4-4o.

As shown on Table 4-4b, 24 metals were detected in Reach 6 surface sediments. Most of the metals were detected in most or all samples. Samples from five stations were analyzed for hexavalent chromium; it was not detected in any of the samples.

The EPA Region 9 PRGs for residential soil were exceeded for seven metals in Reach 6 (arsenic, cadmium, iron, lead, manganese, mercury, and vanadium). Arsenic exceeded the PRG every sample, with concentrations exceeding the PRG by one to four orders of magnitude. Iron and lead exceeded the PRGs in just over half of the samples, with their average concentrations also exceeding the PRGs. Vanadium exceeded the PRG in 12 of 44 samples. The remaining three metals exceeded the PRGs in only one or two samples each. The maximum concentrations of all these metals except arsenic was within one order of magnitude higher than the Region 9 PRG.

As shown on Table 4-4b, the OMEEL SELs were exceeded in Reach 6 for the same nine metals as in Reach 0 (arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, and zinc). Five of these (arsenic, chromium, copper, lead, and zinc) exceeded the criteria in more than half the samples. For most of these metals, the maximum concentration was within one order of magnitude higher than the SEL and the average concentration was in the same order of magnitude or below the criteria. Only arsenic was detected at concentrations more than an order of magnitude above its SEL and its average concentration was an order of magnitude higher than the SEL.

As shown on Table 4-4b, all metals detected in Reach 1 were present at concentrations above their study area average background concentrations. Most of the metals exceeded the background concentrations in more than half the samples in the reach.

Seven metals (arsenic, cadmium, iron, lead, manganese, vanadium, and mercury) exceeded all applicable criteria in sediment from at least one sample location in Reach 6. Figures 4-4n and 4-4o show sample locations in Reach 6 where all applicable criteria were exceeded. As illustrated on Figure 4-4n, arsenic exceeded all applicable criteria at approximately two thirds of the sample locations. Arsenic exceedances occurred at locations throughout both forebays and lakes. As shown on Figure 4-4o more than half of the sample locations in Reach 6 also exceeded all applicable criteria for at least one additional metal. Lead and iron were the most prevalent of the other metals exceeding all criteria.

4.4.2.2 SVOCs – Surface Sediment

The nature and extent of SVOCs detected in surface sediment are discussed below. The results for the study area reference (background) stations data set are presented first, followed by the results for each study area reach, from north to south (upstream to downstream).

Reference Stations Surface Sediment – SVOCs

Surface sediment samples from 26 reference stations were analyzed for SVOCs. The reference stations were located in areas representative of study area habitats, but not likely to be impacted by site- or other-contaminant sources (Figures 2-7I and 2-7J). Reference data summary statistics and comparisons to reference criteria are presented in Table 4-4a. Complete analytical data are presented in Appendix 4-4C.

As shown on Table 4-4a, 25 SVOCs, primarily PAHs, were detected in reference station surface sediments. Ten of the compounds were detected in the majority of samples; the rest were detected in fewer than 50 percent of samples.

The EPA Region 9 PRGs for residential soil were exceeded for six PAHs in the reference station sediment [benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene]. Two compounds [benzo(k)fluoranthene and indeno(1,2,3-cd)pyrene] exceeded the PRG in less than a quarter of the samples. The other four exceeded the PRGs in 40 to 70 percent of the samples. The average concentrations of all except benzo(k)fluoranthene also exceeded the Region 9 PRG.

As shown on Table 4-4a, the OMEE SELs for SVOCs were not exceeded in reference station sediment.

Summary of Study Area – Surface Sediment SVOCs

A total of 124 surface sediment samples were collected from throughout the RI study area and analyzed for SVOCs. Approximately 40 percent of the samples were collected from the Wells G&H wetlands in Reach 1, with the remaining samples distributed among sediment deposition areas throughout the rest of the study area.

Twenty three SVOCs, primarily PAHs, were detected in study area surface sediment samples. The highest concentrations of SVOCs were generally found in Reach 3 and the highest frequencies of exceedance of reference criteria were found in Reaches 0 and 3. Five PAHs [benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene] exceeded Region 9 PRGs in all study area reaches, and the reference stations. Concentrations of most SVOCs detected in study area samples were in the same order of magnitude as or lower than the concentrations detected in the reference station samples. Only Reach 3 had a significant fraction of samples with SVOC concentrations exceeding maximum background concentrations. The OMEE SELs for SVOCs were not exceeded in any study area surface sediment samples.

Two SVOCs were present in the study area at concentrations exceeding all applicable criteria. Benzo(b)fluoranthene concentrations exceeded all criteria in at least one sample from every reach. Bis(2-ethylhexyl)phthalate exceeded all criteria at only one location in Reach 0. Figures 4-4p through 4-4w show sample locations in each reach where all applicable criteria were exceeded for organics.

Additional details of the nature and extent of SVOCs contamination in individual study area reaches are provided in the sections below. Summary statistics and comparisons to reference criteria for SVOCs in surface sediment are presented in Table 4-4c. Complete analytical data are presented in Appendix 4C.

Reach 0 Surface Sediment – SVOCs

Surface sediment samples were collected from seven sample stations in Reach 0 and analyzed for SVOCs. Summary statistics and comparisons to reference criteria are presented in Table 4-4c. Sample locations in Reach 0 where SVOCs concentrations exceed all applicable reference criteria are presented on Figure 4-4p.

As shown on Table 4-4c, 23 SVOCs, primarily PAHs, were detected in Reach 0 surface sediments. Most of the SVOCs were detected in most or all samples.

The EPA Region 9 PRGs for residential soil were exceeded for seven SVOCs in Reach 0 [benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene,

dibenzo(a,h)anthracene, indeno(1,2,3-cd)pyrene, and bis(2-ethylhexyl)phthalate]. Two of these compounds [benzo(k)fluoranthene and bis(2-ethylhexyl)phthalate] exceeded the PRG in only one sample. Benzo(a)pyrene exceeded the PRGs in all seven samples; with the detected concentrations all ranging from one to two orders of magnitude higher than the PRG. The other four compounds all exceeded the PRG in at least six of the seven samples. The maximum and average concentrations of these four SVOCs exceeded the Region 9 PRG by one or two orders of magnitude.

As shown on Table 4-4c, the OMEE SELs for SVOCs were not exceeded in the Reach 0 surface sediment samples.

As shown on Table 4-4c, nearly all SVOCs detected in Reach 0 were present in at least one sample at concentrations above their study area average background concentrations. Approximately half of the SVOCs exceeded the background concentrations in more than half the samples in the reach, most of the others exceeded average background in only one sample.

Two SVOCs [benzo(b)fluoranthene and bis(2-ethylhexyl)phthalate] were present in Reach 0 at concentrations exceeding all applicable criteria. Benzo(b)fluoranthene concentrations exceeded applicable criteria in five of seven sample locations. Bis(2-ethylhexyl)phthalate also exceeded the applicable criteria at one sample location. Figure 4-4p shows sample locations in Reach 0 where all applicable criteria were exceeded for organics.

Reach 1 Surface Sediment – SVOCs

Surface sediment samples were collected from 48 sample stations in Reach 1 and analyzed for SVOCs. Summary statistics and comparisons to reference criteria are presented in Table 4-4c. Sample locations in Reach 1 where SVOCs concentrations exceed all applicable reference criteria are presented on Figure 4-4q.

As shown on Table 4-4c, 21 SVOCs, primarily PAHs, were detected in Reach 1 surface sediments. Most of the SVOCs were detected in more than half samples.

The EPA Region 9 PRGs for residential soil were exceeded for five SVOCs in Reach 1 [benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, dibenzo(a,h)anthracene, and

indeno(1,2,3-cd)pyrene]. Benzo(a)pyrene exceeded the PRGs in every sample where it was detected (30 of 38 samples); with the detected concentrations all ranging from one to two orders of magnitude higher than the PRG. Benzo(b)fluoranthene also exceeded the PRGs in more than half the samples, with average and maximum concentrations exceeding the PRGs by one order of magnitude. The other three compounds exceeded the PRGs in 20 to 40 percent of the samples. The average concentrations of these three SVOCs were in the same order of magnitude as their Region 9 PRGs and their maximum concentrations were one order of magnitude higher than the PRGs.

As shown on Table 4-4c, the OMEE SELs for SVOCs were not exceeded in the Reach 1 surface sediment samples.

As shown on Table 4-4c, more than half of the SVOCs detected in Reach 1 were present in at least one sample at concentrations above their study area average background concentrations. Only one of the SVOCs [bis(2-ethylhexyl)phthalate] exceeded the background concentrations in more than half the samples in the reach. The rest exceeded average background concentrations in fewer than one fourth of the samples.

Benzo(b)fluoranthene was the only SVOC present in Reach 1 at concentrations exceeding all applicable criteria. It exceeded the criteria at 10 of the 48 sample locations. Figure 4-4q shows sample locations in Reach 1 where all applicable criteria were exceeded for organics. All of the exceedances occurred in the Aberjona River channel or the wetlands west of the river.

Reach 2N Surface Sediment – SVOCs

Surface sediment samples were collected from 16 sample stations in Reach 2N and analyzed for SVOCs. Summary statistics and comparisons to reference criteria are presented in Table 4-4c. Sample locations in Reach 2N where SVOCs concentrations exceed all applicable reference criteria are presented on Figure 4-4r.

As shown on Table 4-4c, 20 SVOCs, primarily PAHs, were detected in Reach 2N surface sediments. Half of the SVOCs were detected in only one or two samples, most of the remaining SVOCs were detected in two thirds or more of the samples. The highest concentration of all but one SVOC was detected in the same sample (SD-09-06-FW).

The EPA Region 9 PRGs for residential soil were exceeded for four SVOCs in Reach 2N [benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, and dibenzo(a,h)anthracene]. Only benzo(a)pyrene exceeded the PRGs in more than half the samples; its average and maximum concentrations exceeded the PRGs by one and two orders of magnitude, respectively. The other three compounds exceeded the PRGs in only one or two of the samples, with their maximum concentrations within one order of magnitude higher than the PRG.

As shown on Table 4-4c, the OMEE SELs for SVOCs were not exceeded in the Reach 2N surface sediment samples.

As shown on Table 4-4c, 9 of the 20 SVOCs detected in Reach 2N were present at above their study area average background concentration in one sample. The remaining compounds were not present at concentrations exceeding the background.

Benzo(b)fluoranthene was the only SVOC present in Reach 2N at concentrations exceeding all applicable criteria. It exceeded the criteria at only one sample location (SD-09-06-FW). Figure 4-4r shows sample locations in Reach 2N where all applicable criteria were exceeded for organics.

Reach 2S Surface Sediment – SVOCs

Surface sediment samples were collected from three sample stations in Reach 2S and analyzed for SVOCs. Summary statistics and comparisons to reference criteria are presented in Table 4-4c. Sample locations in Reach 2S where SVOCs concentrations exceed all applicable reference criteria are presented on Figure 4-4s.

As shown on Table 4-4c, 19 SVOCs, primarily PAHs, were detected in Reach 2S surface sediments. Most of the SVOCs were detected in all three samples. The highest concentration of most of the compounds was detected in the same sample (SD-08-02-FW).

The EPA Region 9 PRGs for residential soil were exceeded for five SVOCs in Reach 2S [benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene]. Benzo(a)pyrene and benzo(b)fluoranthene exceeded the PRGs in all

three samples; with maximum concentrations one order of magnitude higher than the PRG. The other three compounds each exceeded the PRGs in only one sample, with their maximum concentrations in the same or one order of magnitude higher than the PRG.

As shown on Table 4-4c, the OMEE SELs for SVOCs were not exceeded in the Reach 2S surface sediment samples.

As shown on Table 4-4c, three of the SVOCs detected in Reach 2S were present at above their study area average background concentration in one sample. The remaining compounds were not present at concentrations exceeding the background.

Benzo(b)fluoranthene was the only SVOC present in Reach 2S at concentrations exceeding all applicable criteria. It exceeded the criteria at only one sample location (SD-08-02-FW). Figure 4-4s shows sample locations in Reach 2S where all applicable criteria were exceeded for organics.

Reach 3 Surface Sediment – SVOCs

Surface sediment samples were collected from 13 sample stations in Reach 3 and analyzed for SVOCs. Summary statistics and comparisons to reference criteria are presented in Table 4-4c. Sample locations in Reach 3 where SVOCs concentrations exceed all applicable reference criteria are presented on Figure 4-4t.

As shown on Table 4-4c, 23 SVOCs, primarily PAHs, were detected in Reach 3 surface sediments. Most of the SVOCs were detected in most or all the samples.

The EPA Region 9 PRGs for residential soil were exceeded for six SVOCs in Reach 3 [benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene]. Benzo(a)pyrene exceeded the PRGs in all 13 samples; with the detected concentrations ranging from one to three orders of magnitude higher than the PRG. Benzo(k)fluoranthene exceeded the PRGs in only 3 of the 13 samples; its average concentration was lower than the PRG and its maximum exceeded the PRG by one order of magnitude. The remaining four compounds exceeded the PRGs in 9 to 12 of the

samples, with average concentrations exceeding the PRGs by one order of magnitude and maximum concentrations exceeding the PRGs by up to two orders of magnitude.

As shown on Table 4-4c, the OMEE SELs for SVOCs were not exceeded in the Reach 3 surface sediment samples.

As shown on Table 4-4c, 19 of the 23 SVOCs detected in Reach 3 were present in at least one sample at concentrations above their study area average background concentrations. Most of these compounds exceeded the background concentrations in more than two thirds of the samples in the reach.

Benzo(b)fluoranthene was the only SVOC present in Reach 3 at concentrations exceeding all applicable criteria. It exceeded the criteria at 11 of the 13 sample locations. Figure 4-4t shows sample locations in Reach 3 where all applicable criteria were exceeded for organics.

Reach 4 Surface Sediment – SVOCs

Surface sediment samples were collected from five sample stations in Reach 4 and analyzed for SVOCs. Summary statistics and comparisons to reference criteria are presented in Table 4-4c. Sample locations in Reach 4 where SVOCs concentrations exceed all applicable reference criteria are presented on Figure 4-4u.

As shown on Table 4-4c, 19 SVOCs, primarily PAHs, were detected in Reach 4 surface sediments. Most of the SVOCs were detected in more than half of the samples.

The EPA Region 9 PRGs for residential soil were exceeded for five SVOCs in Reach 4 [benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene]. Benzo(a)pyrene exceeded the PRGs in all five samples; with the detected concentrations ranging from one to two orders of magnitude higher than the PRG. The other four compounds exceeded the PRGs in one to four samples, with their maximum concentrations all one order of magnitude higher than the PRGs.

As shown on Table 4-4c, the OMEE SELs for SVOCs were not exceeded in the Reach 4 surface sediment samples.

As shown on Table 4-4c, most of the SVOCs detected in Reach 4 were present at above their study area average background concentration in at least one sample. One compound exceeded the background concentration at 3 of 5 samples, the rest exceed background concentrations in two or fewer samples.

Benzo(b)fluoranthene was the only SVOC present in Reach 4 at concentrations exceeding all applicable criteria. It exceeded the criteria at two of the five sample locations. Figure 4-4u shows sample locations in Reach 4 where all applicable criteria were exceeded for organics.

Reach 5 Surface Sediment – SVOCs

Surface sediment samples were collected from four sample stations in Reach 5 and analyzed for SVOCs. Summary statistics and comparisons to reference criteria are presented in Table 4-4c. Sample locations in Reach 5 where SVOCs concentrations exceed all applicable reference criteria are presented on Figure 4-4v.

As shown on Table 4-4c, 19 SVOCs, all PAHs, were detected in Reach 5 surface sediments. Most of the SVOCs were detected in more than half of the samples.

The EPA Region 9 PRGs for residential soil were exceeded for five SVOCs in Reach 5 [benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene]. Benzo(a)pyrene exceeded the PRGs in all four samples; with the detected concentrations ranging from one to two orders of magnitude higher than the PRG. The other four compounds each exceeded the PRGs in one or two samples, with their maximum concentrations all one order of magnitude higher than the PRGs.

As shown on Table 4-4c, the OMEE SELs for SVOCs were not exceeded in the Reach 5 surface sediment samples.

As shown on Table 4-4c, 11 of the 19 SVOCs detected in Reach 5 were present at above their study area average background concentration in at least one sample. One of these compounds exceeded the background concentration in two of the four samples, the remaining ten exceeded background concentrations in only one sample each.

Benzo(b)fluoranthene was the only SVOC present in Reach 5 at concentrations exceeding all applicable criteria. It exceeded the criteria at one sample location (SD-05-03-FW). Figure 4-4v shows sample locations in Reach 5 where all applicable criteria were exceeded for organics.

Reach 6 Surface Sediment – SVOCs

Surface sediment samples were collected from 28 sample stations in Reach 6 and analyzed for SVOCs. Summary statistics and comparisons to reference criteria are presented in Table 4-4c. Sample locations in Reach 6 where SVOCs concentrations exceed all applicable reference criteria are presented on Figure 4-4w.

As shown on Table 4-4c, 20 SVOCs, primarily PAHs, were detected in Reach 6 surface sediments. Most of the SVOCs were detected in more than half of the samples.

The EPA Region 9 PRGs for residential soil were exceeded for five SVOCs in Reach 6 [benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene]. All detected values for benzo(a)pyrene and dibenzo(a,h)anthracene exceeded the PRGs; with the detected concentrations ranging from the same to two orders of magnitude higher than the PRGs. The other three compounds each exceeded the PRGs in 25 to 35 percent of samples, with their maximum concentrations one order of magnitude higher than the PRGs.

As shown on Table 4-4c, the OMEE SELs for SVOCs were not exceeded in the Reach 6 surface sediment samples.

As shown on Table 4-4c, 16 of the 20 SVOCs detected in Reach 6 were present at above their study area average background concentration in at least one sample. None of these compounds exceeded the background concentration in more than a quarter of the samples.

Benzo(b)fluoranthene was the only SVOC present in Reach 6 at concentrations exceeding all applicable criteria. It exceeded the criteria at 6 of the 28 sample locations. Figure 4-4w shows sample locations in Reach 6 where all applicable criteria were exceeded for organics. The exceedances were most prevalent at the outlet of the Aberjona River in the upper forebay; four of the six samples collected from this area had exceedances of benzo(b)fluoranthene.

4.4.2.3 VOCs – Surface Sediment

The nature and extent of VOCs detected in surface sediment are discussed below. The results for the study area reference (background) stations data set are presented first, followed by the results for each study area reach, from north to south (upstream to downstream). VOC data are evaluated relative to only the EPA Region 9 PRGs and average background concentrations. No OMEE SELs are available for VOCs.

Reference Stations Surface Sediment – VOCs

Surface sediment samples from 26 reference stations were analyzed for VOCs. The reference stations were located in areas representative of study area habitats, but not likely to be impacted by site- or other-contaminant sources (Figures 2-7I and 2-7J). Reference data summary statistics and comparisons to reference criteria are presented in Table 4-4a. Complete analytical results are presented in Appendix 4C.

As shown on Table 4-4c, eight VOCs were detected in reference station surface sediments. Most of the compounds were detected infrequently and all were detected at relatively low concentrations. The EPA Region 9 PRGs for residential soil were not exceeded for any of the detected VOCs. All of the compounds were detected at concentrations at least two orders of magnitude lower than the Region 9 PRGs.

Summary of Study Area – Surface Sediment VOCs

A total of 105 surface sediment samples were collected from throughout the RI study area and analyzed for VOCs. Nearly 60 percent of the samples were collected from the Reaches 1 and 6, with the remaining samples distributed among sediment deposition areas throughout the rest of the study area.

Twenty VOCs were detected in study area surface sediment samples. VOCs were detected in samples from every segment of the study area except Reach 2S. Detected compounds included aromatic compounds, chlorinated aliphatics, and ketones. Eight of the compounds detected in study area samples were also detected in the reference station samples.

Most compounds were detected infrequently and at low concentrations. The most widely detected compounds were tetrachloroethene; cis -1,2-dichloroethene; 2-butanone; and acetone. These were each detected in a total of 20 to 30 study area samples collected from most study area reaches. The ketone compounds were also present in reference samples. The rest of the 20 detected VOCs were detected in 12 or fewer study area samples.

Only four compounds (benzene, tetrachloroethene, trichloroethene, and vinyl chloride) exceeded the EPA Region 9 PRGs for residential soil in at least one sample. Benzene exceeded the PRG in one sample in Reach 0. Tetrachloroethene, trichloroethene, and vinyl chloride exceeded the PRGs in two, five, and one sample, respectively, in Reach 1. These four VOCs also exceeded all applicable reference criteria in at least one sample. These exceedances occurred at seven locations in Reaches 0 and 1. Figures 4-4p and 4-4q show sample locations in Reaches 0 and 1 where all applicable criteria were exceeded for organics. No samples from the rest of the study area contained VOCs at concentrations that exceeded all applicable criteria.

Additional details of the nature and extent of VOCs contamination in individual study area reaches are provided in the sections below. Summary statistics and comparisons to reference criteria for VOCs in surface sediment are presented in Table 4-4c. Sample locations where VOCs concentrations exceeded all applicable reference criteria are shown on Figures 4-4p and 4-4q.

Reach 0 Surface Sediment –VOCs

Surface sediment samples collected from seven sample stations in Reach 0 were analyzed for VOCs. Summary statistics and comparisons to reference criteria are presented in Table 4-4c.

As shown on Table 4-4c, 13 VOCs were detected in Reach 0 surface sediments. Five of these were also detected in the reference station samples. Detected compounds included chlorinated and non-chlorinated aromatics, chlorinated ethenes and ethanes, and ketones. Most of the VOCs were detected infrequently and at low concentrations. Benzene, acetone, and carbon-disulfide were the only compounds detected in more than half of the samples; these were also detected in the reference data set. Only benzene exceeded the EPA Region 9 PRG at one

sample station (SD-MC-05 in HBHA pond) at a concentration of about two orders of magnitude higher than the criterion. No other samples exceeded the Region 9 PRGs for any compounds.

Four VOCs exceeded the average concentrations detected in the background data set. Benzene, acetone, and carbon-disulfide exceeded average background values in four samples each and 2-butanone exceeded average background values in two samples.

The benzene concentration in the sample from SD-MC-05 in HBHA pond was the only VOC that exceeded all applicable reference criteria in any Reach 0 sample. Figure 4-4p shows sample locations in Reaches 0 where all applicable criteria were exceeded for organics.

Reach 1 Surface Sediment –VOCs

Surface sediment samples collected from 34 sample stations in Reach 1 were analyzed for VOCs. Summary statistics and comparisons to reference criteria are presented in Table 4-4c.

As shown on Table 4-4c, 15 VOCs were detected in Reach 1 surface sediments. Six of these were also detected in the reference station samples. Detected compounds included chlorinated ethenes and ethanes; non-chlorinated aromatic compounds; and ketones. Most of the VOCs were detected infrequently and at low concentrations. Only 1,2-dichloroethene (cis- and total), 2-butanone, and acetone were detected in at least half of the samples; the latter two of these were also detected in the reference data set and are common laboratory contaminants.

Three VOCs (tetrachloroethene, trichloroethene, and vinyl chloride) exceeded the EPA Region 9 PRGs in two, five, and one sample respectively. Maximum concentrations of these compounds were up to two orders of magnitude higher than the PRGs. All other VOCs detected were present at concentrations at least an order of magnitude lower than the Region 9 PRGs.

Five VOCs (1,1,1- trichloroethane, 2-butanone, acetone, benzene, and carbon disulfide) exceeded the average concentrations detected in the background data set. Only 2-butanone and acetone exceeded average background values in half or more of the samples; the others exceeded average background values in one or three samples each.

Samples from six locations in Reach 1 contained VOCs at concentrations that exceeded all applicable reference criteria. Two locations exceeded the criteria for tetrachloroethene and trichloroethene. The remaining sample locations exceeded the criteria for only trichloroethene (3 locations) or vinyl chloride (1 location). Figure 4-4q shows sample locations in Reaches 1 where all applicable criteria were exceeded for organics.

Reach 2N Surface Sediment – VOCs

Surface sediment samples collected from 16 sample stations in Reach 2N were analyzed for VOCs. Summary statistics and comparisons to reference criteria are presented in Table 4-4c.

As shown on Table 4-4c, four VOCs (1,1,1-trichloroethane, acetone, toluene, and methyl acetate) were detected in Reach 2N surface sediments; these four VOCs were also detected in the reference samples. Acetone was detected in three Reach 2N samples, the others were detected in only one sample each. The detected concentrations of these compounds were all well below (by at least four orders of magnitude) the EPA Region 9 PRGs, but all exceeded the average concentrations detected in the background data set.

No samples from Reach 2N contained VOCs at concentrations that exceeded all applicable reference criteria.

Reach 2S Surface Sediment – VOCs

No VOCs were detected in the three surface sediment samples from Reach 2S that were analyzed for VOCs.

Reach 3 Surface Sediment – VOCs

Surface sediment samples collected from 12 sample stations in Reach 3 were analyzed for VOCs. Summary statistics and comparisons to reference criteria are presented in Table 4-4c.

As shown on Table 4-4c, four VOCs (trichloroethene; cis-1,2-dichloroethene; 2-butanone; and ethylbenzene) were detected in Reach 3 surface sediments; 2-butanone was also detected in the reference samples. Ethylbenzene was detected in one Reach 3 sample, the others were

detected in three samples each. The detected concentrations of these compounds were all below the EPA Region 9 PRGs. The 2-butanone concentration in one sample exceeded the average concentration detected in the background data set.

No samples from Reach 3 contained VOCs at concentrations that exceeded all applicable reference criteria.

Reach 4 Surface Sediment – VOCs

Surface sediment samples collected from four sample stations in Reach 4 were analyzed for VOCs. Summary statistics and comparisons to reference criteria are presented in Table 4-4c.

As shown on Table 4-4c, seven VOCs (trichloroethene; cis-1,2-dichloroethene; 2-butanone; ethylbenzene; benzene; m&p xylene; and methyl acetate) were detected in Reach 4 surface sediments; three of these were also detected in the reference samples. 2-Butanone was detected in three Reach 4 samples, the other compounds were detected in one sample each. None of the VOCs were detected at concentrations exceeding the EPA Region 9 PRGs. The detected concentration of trichloroethene was slightly lower than the PRG. The other detected VOC concentrations were all at least one order of magnitude below their Region 9 PRGs. The 2-butanone and benzene concentrations in one sample each exceeded the average concentrations detected in the background data set.

No samples from Reach 4 contained VOCs at concentrations that exceeded all applicable reference criteria.

Reach 5 Surface Sediment – VOCs

Surface sediment samples collected from four sample stations in Reach 5 were analyzed for VOCs. Summary statistics and comparisons to reference criteria are presented in Table 4-4c.

As shown on Table 4-4c, seven VOCs (trichloroethene; cis-1,2-dichloroethene; total 1,2-dichloroethene; 2-butanone; ethylbenzene; benzene; and m&p xylene) were detected in Reach 5 surface sediments. Each was detected in one sample at concentrations lower than any applicable reference criteria.

Reach 6 Surface Sediment – VOCs

Surface sediment samples collected from 28 sample stations in Reach 6 were analyzed for VOCs. Summary statistics and comparisons to reference criteria are presented in Table 4-4c.

As shown on Table 4-4c, nine VOCs (trichloroethene; cis-1,2-dichloroethene; 1,1,1-trichloroethane; 2-butanone; acetone; benzene; toluene; methyl acetate; and 1,1,2-trichloro-1,2,2-trifluoroethane) were detected in Reach 6 surface sediments; seven of these were also detected in the reference samples. Five of the VOCs were detected in one sample each, one was detected in six samples, the other compounds were detected in two or three samples each.

None of the VOCs were detected at concentrations exceeding the EPA Region 9 PRGs. The detected concentration of trichloroethene was in the same order of magnitude as the PRG. The other detected VOC concentrations were all at least two orders of magnitude below their Region 9 PRGs. The concentrations of seven VOCs exceeded average concentrations in the background data set in one to three samples each.

No samples from Reach 6 contained VOCs at concentrations that exceeded all applicable reference criteria.

4.4.2.4 Pesticides/PCBs – Surface Sediment

The nature and extent of pesticides and PCBs detected in surface sediment are discussed below. PCBs are reported as aroclors. The results for the study area reference (background) stations data set are presented first, followed by the results for each study area reach, from north to south (upstream to downstream).

Reference Stations Surface Sediment – Pesticides and PCBs

Surface sediment samples from 26 reference stations were analyzed for pesticides and PCBs. The reference stations were located in areas representative of study area habitats, but not likely to be impacted by site- or other-contaminant sources (Figures 2-7I and 2-7J). Reference data summary statistics and comparisons to reference criteria are presented in Table 4-4a.

As shown on Table 4-4a, 18 pesticides and two PCBs were detected in reference station surface sediments. Most of the compounds were detected infrequently. Only three pesticides (4,4'-DDD; 4,4'-DDE; and 4,4'-DDT) were detected in more than half of the samples; all the rest were detected in fewer than one third of the samples. The two PCBs (Aroclor 1248 and Aroclor 1260) were detected in only 2 of 26 samples.

The pesticides and PCBs were all detected at relatively low concentrations. None exceeded the EPA Region 9 PRGs for residential soil or the OMEE SELs. Nearly all compounds were detected at concentrations at least an order of magnitude lower than the Region 9 PRGs and two orders of magnitude lower than the SELs.

Summary of Study Area Surface Sediment – Pesticides and PCBs

A total of 123 surface sediment samples collected from throughout the RI study area were analyzed for pesticides and PCBs. Nearly 65 percent of the samples were collected from the Reaches 1 and 6, with the remaining samples distributed among sediment deposition areas throughout the rest of the study area.

Twenty pesticides and three PCBs were detected in study area surface sediment samples. Pesticides were detected in samples from every segment of the study area. In nearly every reach, several pesticides were detected in more than half of the samples. The most frequently detected compounds were 4,4'-DDD; 4,4'-DDE; and alpha-chlordane. These three pesticides were detected in all study area reaches and were present in more than half of the samples in Reaches 1 through 4. Two PCBs (Aroclors 1248 and 1260) were detected in samples from all study area segments except Reaches 0, 2N, and 2S; neither was detected in more than half of the samples in any reach.

The largest number of pesticides/PCBs, and generally the highest concentrations and greatest frequency of detection of were observed in Reaches 1 and 3. In both of these areas, most of the compounds detected were present in more than half of the samples and most compounds were present at concentrations higher than the average background concentrations in one or more samples.

No pesticides and only one PCB in study area samples exceeded the EPA Region 9 PRG for residential soil (Aroclor 1254 exceeded the PRG in nine samples in Reach 1). No pesticides or PCBs exceeded the OMEE SELs in any study area sample. No study area samples contained any pesticides or PCBs at concentrations that exceeded all applicable criteria.

Additional details of the nature and extent of pesticide and PCB contamination in individual study area reaches are provided in the sections below. Summary statistics and comparisons to reference criteria for pesticides and PCBs in surface sediment are presented in Table 4-4c.

Reach 0 Surface Sediment – Pesticides and PCBs

Surface sediment samples collected from seven sample stations in Reach 0 were analyzed for pesticides and PCBs. Summary statistics and comparisons to reference criteria are presented in Table 4-4c.

As shown on Table 4-4c, four pesticides (4,4'-DDD; 4,4'-DDE; alpha-chlordane; and gamma-chlordane) and no PCBs were detected in Reach 0 surface sediments. Each of the pesticides was detected in only one or two samples. All four of the detected compounds were also detected in the reference samples.

None of the compounds were detected at concentrations exceeding the EPA Region 9 PRGs or OMEE SELs. The detected concentrations were well (at least two orders of magnitude) below these criteria. The only exceedances of any reference criteria for pesticides or PCBs in Reach 0 were concentrations of alpha- and gamma-chlordane, which exceeded the average background concentrations in one sample each.

No samples from Reach 0 contained pesticides or PCBs at concentrations that exceeded all applicable reference criteria. Samples that were analyzed for pesticides/PCBs in Reach 0 are identified on Table 2-4 and shown on Figure 4-4p.

Reach 1 Surface Sediment – Pesticides and PCBs

Surface sediment samples collected from 50 sample stations in Reach 1 were analyzed for pesticides and/or PCBs. Summary statistics and comparisons to reference criteria are presented in Table 4-4c.

As shown on Table 4-4c, 17 pesticides and three PCBs were detected in Reach 1 surface sediments. The compounds were detected in samples from throughout Reach 1. Nine of the pesticides and one PCB were detected in more than half of the samples; most of the remaining compounds were detected in fewer than one quarter of the samples. Most of the detected compounds were also detected in the reference samples.

One PCB (Aroclor 1254) exceeded the EPA Region 9 PRG for residential soil in nine samples in Reach 1. The exceedances were all observed in the JY-series samples along the southern edge of the wetland, adjacent to an automobile junk yard. The highest concentrations of the other detected PCBs were also found in these sample stations. No PCBs exceeded the OMEE SELs. Aroclors 1248 and 1260 were each present in several samples at concentrations higher than the average background concentrations.

No pesticides exceeded the EPA Region 9 PRGs or OMEE SELs in any Reach 1 sample. Most of the detected concentrations were at least an order of magnitude below these criteria. The only reference criteria exceeded for pesticides in Reach 1 were the average background concentrations. Several pesticides exceeded the average background concentrations in some samples; most exceeded background concentrations in fewer than a quarter of the samples.

No samples from Reach 1 contained pesticides or PCBs at concentrations that exceeded all applicable reference criteria. Samples that were analyzed for pesticides/PCBs are identified on Tables 2-4 and 2-5 and shown on Figure 4-4q.

Reach 2N Surface Sediment – Pesticides and PCBs

Surface sediment samples collected from 15 sample stations in Reach 2N were analyzed for pesticides and PCBs. Summary statistics and comparisons to reference criteria are presented in Table 4-4c.

As shown on Table 4-4c, 15 pesticides were detected at relatively low concentrations in Reach 2N surface sediments. Seven of the pesticides were detected in more than half of the samples; most of the remaining compounds were detected in fewer than one third of the samples. Most of the detected compounds were also detected in the reference samples. No PCBs were detected in Reach 2N surface sediments.

None of the pesticides were detected at concentrations exceeding the EPA Region 9 PRGs or OMEE SELs in any Reach 2N sample. All of the detected concentrations were at least an order of magnitude below these criteria. The only reference criteria exceeded for pesticides in Reach 2N were the average background concentrations. Two pesticides exceeded the average background concentrations in a total of three samples.

No samples from Reach 2N contained pesticides or PCBs at concentrations that exceeded all applicable reference criteria. Samples that were analyzed for pesticides/PCBs are identified on Table 2-5 and shown on Figure 4-4r.

Reach 2S Surface Sediment – Pesticides and PCBs

Surface sediment samples collected from three sample stations in Reach 2S were analyzed for pesticides and PCBs. Summary statistics and comparisons to reference criteria are presented in Table 4-4c.

As shown on Table 4-4c, 14 pesticides were detected at relatively low concentrations in Reach 2S surface sediments. Six of the pesticides were detected in two or three samples each; the rest were detected in one sample each. Most of the detected compounds were also detected in the reference samples. No PCBs were detected in Reach 2S surface sediments.

None of the pesticides detected in the Reach 2S samples exceeded any of the reference criteria. All of the detected concentrations were at least an order of magnitude below the EPA Region 9 PRGs and OMEE SELs and most were an order of magnitude below the average background concentrations.

No samples from Reach 2S contained pesticides or PCBs at concentrations that exceeded all applicable reference criteria. Samples that were analyzed for pesticides/PCBs are identified on Table 2-5 and shown on Figure 4-4s.

Reach 3 Surface Sediment – Pesticides and PCBs

Surface sediment samples collected from 13 sample stations in Reach 3 were analyzed for pesticides and PCBs. Summary statistics and comparisons to reference criteria are presented in Table 4-4c.

As shown on Table 4-4c, 19 pesticides and two PCBs were detected in Reach 3 surface sediments. Twelve of the pesticides were detected in more than half of the samples; most of the remaining compounds, including the two PCBs were detected in only two or three samples each. Most of the detected compounds were also detected in the reference samples.

None of the pesticides or PCBs detected in the Reach 3 samples exceeded the EPA Region 9 PRGs or OMEE SELs. All of the detected concentrations were at least an order of magnitude below these criteria. The only reference criteria exceeded for pesticides and PCBs in Reach 3 were the average background concentrations. Most of the pesticides and both detected PCBs exceeded the average background concentrations in some samples. Three pesticides exceeded background concentrations in more than half of the samples, most of the rest exceeded background values in fewer than a third of the samples.

No samples from Reach 3 contained pesticides or PCBs at concentrations that exceeded all applicable reference criteria. Samples that were analyzed for pesticides/PCBs are identified on Table 2-5 and shown on Figure 4-4t.

Reach 4 Surface Sediment – Pesticides and PCBs

Surface sediment samples collected from five sample stations in Reach 4 were analyzed for pesticides and PCBs. Summary statistics and comparisons to reference criteria are presented in Table 4-4c.

As shown on Table 4-4c, eight pesticides and two PCBs were detected in Reach 4 surface sediments. Three of the pesticides were detected in four or five of the samples; most of the remaining compounds, including the two PCBs were detected in one sample each. Most of the detected compounds were also detected in the reference samples.

None of the pesticides or PCBs detected in the Reach 4 samples exceeded the EPA Region 9 PRGs or OMEE SELs. All of the detected concentrations were at least an order of magnitude below these criteria. The only reference criteria exceeded for pesticides or PCBs in Reach 4 were the average background concentrations. Three of the pesticides exceeded the average background concentrations in four of the five samples; the remaining pesticides and the PCBs each exceeded the background concentrations in one sample.

No samples from Reach 4 contained pesticides or PCBs at concentrations that exceeded all applicable reference criteria. Samples that were analyzed for pesticides/PCBs are identified on Table 2-5 and shown on Figure 4-4u.

Reach 5 Surface Sediment – Pesticides and PCBs

Surface sediment samples collected from two sample stations in Reach 5 were analyzed for pesticides and PCBs. Summary statistics and comparisons to reference criteria are presented in Table 4-4c.

As shown on Table 4-4c, seven pesticides and two PCBs were detected in Reach 5 surface sediments. Each of the compounds was detected in one sample. Most of the detected compounds were also detected in the reference samples.

None of the pesticides or PCBs detected in the Reach 5 samples exceeded the EPA Region 9 PRGs or OMEE SELs. All of the detected concentrations were at least an order of magnitude below these criteria. The only reference criteria exceeded for pesticides or PCBs in Reach 5 were the average background concentrations. All but two of the detected pesticides/PCBs concentrations exceeded the average background concentrations.

No samples from Reach 5 contained pesticides or PCBs at concentrations that exceeded all applicable reference criteria. Samples that were analyzed for pesticides/PCBs are identified on Table 2-5 and shown on Figure 4-4v.

Reach 6 Surface Sediment – Pesticides and PCBs

Surface sediment samples collected from 28 sample stations in Reach 6 were analyzed for pesticides and PCBs. Summary statistics and comparisons to reference criteria are presented in Table 4-4c.

As shown on Table 4-4c, 13 pesticides and two PCBs were detected in Reach 6 surface sediments. Most of the compounds, including the two PCBs were detected in fewer than 30 percent of the samples; none was detected in more than half of the samples. Most of the detected compounds were also detected in the reference samples.

None of the pesticides or PCBs detected in the Reach 6 samples exceeded the EPA Region 9 PRGs or OMEE SELs. All of the detected concentrations were at least an order of magnitude below these criteria. The only reference criteria exceeded for pesticides or PCBs in Reach 6 were the average background concentrations. Two pesticides and both PCBs exceeded the average background concentrations in most of the samples where they were detected; three other pesticides each exceeded the background concentrations two or three samples.

No samples from Reach 6 contained pesticides or PCBs at concentrations that exceeded all applicable reference criteria. Samples that were analyzed for pesticides/PCBs are identified on Table 2-5 and shown on Figure 4-4w.

4.4.3 Sediment Core Samples

Sediment core samples were collected from 13 locations throughout the RI study area in February 2003 to better evaluate the depth of contaminated sediment in the study area. Four samples were collected from each location, in 1-foot intervals from the sediment surface to a depth of 4 feet. All samples were analyzed for metals. See Section 2.2.3.1 and Table 2-5 for additional investigation details. Sediment core locations are shown on Figure 4-4x.

Twenty-two metals were detected in the sediment core samples. Most of the metals were detected in the majority of samples and 10 of the metals were detected in more than 90 percent of samples. In general the highest concentrations were detected in samples from the 0- to 1-foot depth interval. However, metals concentrations exceeding the reference criteria were detected at all depth intervals. Contaminant concentrations did not exhibit a clear pattern from north to south in the study area. Concentrations above all reference criteria were detected from samples throughout the study area, but the highest concentrations and most exceedances of criteria generally occurred at Stations 2, 5, 6, and 12. Arsenic was the most prevalent of the metals exceeding all reference criteria. It was the only one that exceeded all applicable criteria in at least one sample from every station and it exceeded all criteria in all four depth intervals at six stations. Lead was the next most prevalent of the metals exceeding all criteria, followed by iron. Lead exceeded all criteria at 7 of the 13 stations, iron at 5 stations.

The analytical results for each sediment depth interval are discussed in the sections below. Summary statistics and comparisons to reference concentrations are presented in Table 4-4d. Complete analytical data for sediment core samples are presented in Appendix 4C. Sample locations where metals concentrations exceed all applicable reference criteria are shown on Figure 4-4x.

Sediment Core Samples - 0- to 1-foot depth interval

As shown on Table 4-4d, 20 metals were detected in samples in the 0- to 1-foot depth interval. All but four of the metals were detected in at least 10 of the 13 samples.

The EPA Region 9 PRGs for residential soil were exceeded for six metals (arsenic, iron, lead, manganese, mercury, and vanadium) in the 0- to 1-foot depth interval. Arsenic exceeded the PRG in all 13 samples, with concentrations exceeding the PRG by two to four orders of magnitude. Iron exceeded the PRG in 8 of the 13 samples, with the average concentration of all samples also exceeding the PRG. The remaining metals exceeded the PRGs in one to five samples each, with nearly all of the detected concentrations in the same order of magnitude or lower than the Region 9 PRG.

As shown on Table 4-4d, the OMEE SELs were exceeded for nine metals (arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, and zinc) in the 0- to 1-foot depth interval.

Arsenic, chromium, and copper exceeded the criteria in 13, 12, and 11 samples respectively. The other metals exceeded the SELs in 3 to 9 samples each.

As shown on Table 4-4d, all metals detected the 0- to 1-foot depth interval samples were present at concentrations above their study area average background concentrations. Most of the metals exceeded the background concentrations in more than half of the samples.

Six metals (arsenic, iron, lead, manganese, mercury, and vanadium) exceeded all applicable criteria in sediment from at least one sample location in the 0- to 1-foot depth interval. As shown on Figure 4-4x, arsenic exceeded all applicable criteria in the zero to one foot sample at every station and iron and lead exceeded all criteria at four and five samples, respectively. The remaining metals exceeded all criteria in one or two samples.

Sediment Core Samples - 1- to 2-foot depth interval

As shown on Table 4-4d, 19 metals were detected in samples in the 1- to 2-foot depth interval. All but five of the metals were detected in at least 10 of the 13 samples.

The EPA Region 9 PRGs for residential soil were exceeded for five metals (arsenic, cadmium, iron, lead, and mercury) in the one to two foot depth interval. Arsenic exceeded the PRG in 12 of the 13 samples, with concentrations exceeding the PRG by two to four orders of magnitude. The remaining metals exceeded the PRGs in one to five samples each, with nearly all of the detected concentrations in the same order of magnitude or lower than the Region 9 PRG.

As shown on Table 4-4d, the OMEE SELs were exceeded for nine metals (arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, and zinc) in the 1- to 2-foot depth interval. Arsenic, chromium, copper, and zinc each exceeded the criteria in seven or eight samples. The other metals exceeded the SELs in one to five samples each.

As shown on Table 4-4d, all metals detected the 1- to 2-foot depth interval samples were present at concentrations above their study area average background concentrations. Most of the metals exceeded the background concentrations in more than half of the samples.

Five metals (arsenic, cadmium, iron, lead, and mercury) exceeded all applicable criteria in sediment from at least one sample location in the 1- to 2-foot depth interval. As shown on Figure 4-4x, arsenic exceeded all applicable criteria in the one to two foot sample at eight stations. The remaining metals exceeded all criteria at one or two sample stations.

Sediment Core Samples - 2- to 3-foot depth interval

As shown on Table 4-4d, 21 metals were detected in samples in the two to three foot depth interval. Twelve of the metals were detected in at least 10 of the 13 samples.

The EPA Region 9 PRGs for residential soil were exceeded for four metals (arsenic, iron, lead, and mercury) in the 2- to 3-foot depth interval. Arsenic exceeded the PRG in 9 of the 13 samples, with concentrations exceeding the PRG by two to three orders of magnitude. The remaining metals exceeded the PRGs in one to three samples each, with nearly all of the detected concentrations in the same order of magnitude or lower than the Region 9 PRG.

As shown on Table 4-4d, the OMEE SELs were exceeded for eight metals (arsenic, cadmium, chromium, copper, iron, lead, mercury, and zinc) in the 2- to 3-foot depth interval. Arsenic, exceeded the criteria in 9 of the 13 samples. The other metals each exceeded the SELs in fewer than half of the samples.

As shown on Table 4-4d, all metals detected the 2- to 3-foot depth interval samples were present at concentrations above their study area average background concentrations. Only four of the metals exceeded the background concentrations in more than half of the samples.

Four metals (arsenic, iron, lead, and mercury) exceeded all applicable criteria in sediment from at least one sample location in the 2- to 3-foot depth interval. As shown on Figure 4-4x arsenic exceeded all applicable criteria at nine sample stations. The remaining metals exceeded all criteria in one or three samples each.

Sediment Core Samples - 3- to 4-foot depth interval

As shown on Table 4-4d, 21 metals were detected in samples in the 3- to 4-foot depth interval. Ten of the metals were detected in at least 10 of the 13 samples.

The EPA Region 9 PRGs for residential soil were exceeded for five metals (arsenic, iron, lead, mercury, and vanadium) in the 3- to 4-foot depth interval. Arsenic exceeded the PRG in 9 of the 13 samples, with concentrations exceeding the PRG by two to three orders of magnitude. The remaining metals exceeded the PRGs in one to three samples each, with nearly all of the detected concentrations in the same order of magnitude or lower than the Region 9 PRG.

As shown on Table 4-4d, the OMEE SELs were exceeded for seven metals (arsenic, cadmium, chromium, copper, lead, mercury, and zinc) in the 3- to 4-foot depth interval. Arsenic, exceeded the criteria in 7 of the 13 samples. The other metals each exceeded the SELs in fewer than half of the samples.

As shown on Table 4-4d, all metals detected the 3- to 4-foot depth interval samples were present at concentrations above their study area average background concentrations. Only three of the metals exceeded the background concentrations in more than half of the samples.

Four metals (arsenic, lead, mercury, and vanadium) exceeded all applicable criteria in sediment from at least one sample location in the 3- to 4-foot depth interval. As shown on Figure 4-4x, arsenic exceeded all applicable criteria at seven sample locations. The remaining metals exceeded all criteria in one or two samples each.

4.5 Surface Water Contamination

As described in Section 2, several surface water investigations were conducted by the ISRT and EPA between 1995 and 2002 to evaluate the presence and transport of dissolved and suspended contaminants in surface water throughout the RI Study Area. The studies included:

- a comprehensive monitoring program implemented by TtNUS on behalf of EPA to monitor flow parameters and metals transport in the HBHA and Aberjona River during base flow and storm flow conditions (See Section 2.2.2.2);
- comprehensive monitoring programs conducted by Arcadis and Roux on behalf of the ISRT to evaluate hydraulic conditions and monitor flow, surface water quality, and contaminant transport in the HBHA during base flow and storm flow conditions (See Sections 2.1.5.3 and 2.1.5.4); and

- investigations by Foster Wheeler on behalf of EPA (See Section 2.2.2.1) and Menzie-Cura on behalf of ISRT (See Section 2.1.5.5) that included collection of surface water and associated media (sediment, plants, benthic invertebrates) samples from stations throughout the RI Study Area to obtain comprehensive data necessary to assess ecological and human health impacts from contaminated media.

The results of these studies are presented separately in Section 4.5.1 through 4.5.3.

4.5.1 Surface Water Contamination and Contaminant Transport Throughout the RI Study Area under Base Flow and Storm Flow Conditions

As described in Section 2.2.2.2, a surface water monitoring program was implemented by TtNUS on behalf of the EPA to evaluate streamflow and heavy metals and suspended sediment transport in the HBHA and Aberjona River under baseflow and storm flow conditions. The monitoring period for the study covered an 18-month time frame beginning in May 2001 and ending in October 2002. The monitoring program included collection of precipitation, stream flow, and water quality data at 10 monitoring stations located throughout the RI Study Area. (Figure 2-5g). Note: The monitoring stations used in this investigation are referred to as SW-01-TT through SW-10-TT on the analytical data tables and figures in this RI Report to differentiate them from similarly named sampling stations used in other investigations; for ease of discussion, they are referred to within this section simply as Stations 1 through 10.

TtNUS constructed, operated, and maintained automated surface water sampling/monitoring equipment at each of these stations. Semi-continuous (every 15 minutes) measurements of nine physio-chemical parameters (rainfall, stream velocity, water level, water temperature, specific conductance, dissolved oxygen concentration, pH, ORP, and turbidity) were collected at each monitoring station throughout the 18-month monitoring period. Additionally, surface water samples from each station were collected and analyzed for total suspended solids (TSS) and metals (dissolved and total) during 16 monthly baseflow monitoring events and six storm events. Storm events ranged in size from 1 to 2.8 inches of rainfall and occurred in spring, summer, and fall. Composite samples were collected during storm events at eight of the monitoring stations and grab samples were collected hourly during storm events at two monitoring stations (Stations 4 and 8).

Details of the surface water monitoring program and a comprehensive evaluation of the monitoring data are presented in the *Draft Evaluation of Flow, Suspended Sediment, and Heavy Metals in the Aberjona River* (TtNUS, January 2005) presented in Appendix 2C. Section 4.5.1.1 presents a summary of the conclusions of the *Draft Evaluation*. Section 4.5.1.2 presents a summary of the surface water contaminant data in comparison to Ambient Water Quality Criteria (AWQC).

4.5.1.1 Evaluation of Flow, Suspended Sediment, and Heavy Metals Transport

This section presents a summary of the conclusions of the *Draft Evaluation of Flow, Suspended Sediment, and Heavy Metals in the Aberjona River* (TtNUS, January 2005). Refer the full report in Appendix 2C for the comprehensive evaluation. Although samples collected during the study were analyzed for 23 elements, the evaluation focused on the results for six: arsenic, iron, chromium, copper, lead, and mercury. These metals were chosen because they were considered to represent a possible health risk or, in the case of iron, they may impact the transport of metals that could represent a possible health risk. Among the six metals evaluated, much of the discussion focuses on arsenic since it is a primary COC for the Industri-plex Site and preliminary assessments suggest that this metalloid poses the greatest health risk.

Watershed Geometry and Location of Monitoring Stations

Three monitoring stations (Stations 1, 2, and 4) were located within the drainage basin of Halls Brook, a major tributary to the northern reach of the Aberjona River; five stations (Stations 3 and 5 through 8) were located along the main artery of the Aberjona River; and two stations (Stations 9 and 10) were located downstream of the Aberjona River within the Mystic Lakes drainage basin (Figure 2-5g). Of note is that Station 3 was located in the Aberjona River upstream of its confluence with Halls Brook and Station 4 was located at the base of the HBHA upstream of its confluence with the Aberjona River. Flows that passed through Station 3 and 4, joined after these stations and flowed toward Station 5. Thus the “main train” stations originate in Halls Brook and run downstream through the HBHA and the Aberjona River in the following order: Station 1, 2, 4, 5, 6, 7, and 8. Flows from Station 3 join flows from Station 4 between Stations 4 and 5. The density of monitoring stations was higher within the northern part of the watershed. The drainage areas between stations were smaller in the northern part of the watershed in comparison with the southern part (Table 4-5a).

Evaluation of Physio-Chemical Parameters

Comparison of the hydrologic measurements collected during the investigation with historical records indicates that the TtNUS monitoring period was consistent with overall average precipitation and river flow conditions. Both the average depth of rain and frequency of storms were similar between the 104-year record evaluated and the TtNUS period of record. Streamflow measured at TtNUS Station 8 was also consistent with the 63-year average streamflows measured at this site by the U.S. Geological Survey, with the exception of the timing of the spring snowmelt peak.

The total amount of rainfall measured during the 18-month monitoring period was 53 inches, on average. Less rainfall was generally observed at the stations located south of the watershed boundary. Overall average flow measured at Station 8 was 26 cfs. In general, flow was observed to increase in the downstream direction, with the exception of flow between Stations 2 and 4. The drainage area normalized flow for each station ranged from 0.9 to 1.4 cfs/mi² (Table 4-5a).

Semi-continuous measurements of physio-chemical parameters in surface water indicate that water temperature, specific conductivity, and dissolved oxygen content remained reasonably consistent throughout the length of the Aberjona River, but varied with seasonal changes in climate. On average, slightly warmer water temperatures were measured toward the southern part of the watershed. Specific conductivity was observed to increase during the winter months, presumably due to roadway salting activities during this season. Dissolved oxygen levels were also higher during the winter months, presumably due to the higher equilibrium saturation levels in colder waters. pH was fairly consistent throughout the seasons. pH at the stations located within the Aberjona River watershed was generally near 7. Within the Mystic Lakes watershed (Stations 9 and 10), pH was slightly higher, near 8. In general, positive ORP values were observed at all stations with the exception of water at Station 2, which was characterized by negative ORP values (silver/silver-chloride reference), on average (Table 4-5a).

Evaluation of Total Suspended Solids Data

Total suspended solids (TSS) concentrations during baseflow conditions were consistently near 5 mg/L for all stations with the exception of Station 4, which had an average TSS of 22.5 mg/L

(Table 4-5b). The TSS characteristics at Station 4 were unique; during baseflow conditions TSS was subject to significant variability (4 to 110 mg/L) that was not observed at other stations. The elevated TSS concentrations at Station 4 were observed during the fall and early winter months. These elevated levels may be due to turnover of a small pond (HBHA Wetland Pond 3) located immediately upstream of this station.

During storm events, TSS concentrations were higher than during baseflow for all stations located along the Aberjona River with the exception of Station 4. TSS behavior at Station 4 was again unique; the average concentration during storm flow conditions (13 mg/L) was lower than the average TSS concentration during baseflow conditions (21 mg/L). The HBHA wetland immediately upstream of Station 4, including HBHA Wetland Pond No. 3, may play a role in the unique characteristics of TSS observed at this station. Storm event average TSS concentrations for Stations 1 through 8 ranged from 6 to 46 mg/L, with the highest average concentrations at Station 1 (22 mg/L) and Station 8 (46 mg/L). TSS concentrations at Stations 9 and 10 remained relatively constant at approximately 4 mg/L during storm events. Thus, suspended sediment concentrations were not largely affected by flow conditions at these stations, possibly because they were located downstream of the Mystic Lakes which serve to buffer changes in suspended sediment concentrations.

During baseflow conditions, TSS fluxes (the mass of TSS in the flow stream in kg/hr) generally increased in the downstream direction with the exception of the area between the Stations 3/4 confluence and Station 5, where TSS fluxes decreased presumably due to the deposition of suspended sediment in this area. TSS fluxes increased at all stations during storm flow conditions (Table 4-5c). The most notable increases were observed at Stations 1 (0.5 to 21 kg/hr) and 8 (7 to 470 kg/hr). At these stations the TSS flux increased during storms by a factor of 40 (Station 1) and 70 (Station 8) times higher than those observed during baseflow conditions. These increases are a combined effect of increased flows and TSS concentrations observed at these stations during storm conditions.

TSS fluxes were notably high at Station 8 during storm flow conditions, indicating a strong TSS flushing effect at this station during storm conditions. This strong flushing effect was noted even when the TSS flux was normalized by the drainage area contributing to this station (Table 4-5d). One factor that may have influenced storm event TSS concentrations (as well as metal concentrations) at this station may be the capture of the “first flush”. This station had a very

large drainage area, much larger than stations upstream, and was thus slower to respond during storm events. The probability of capturing the first flush was higher at this station relative to the others, as a result of a slower response. The highest TSS and metals concentrations observed in the river were associated with the very first samples collected at Station 8 during the May 2002 storm event. These samples drove the higher overall TSS concentrations and fluxes at Station 8 during storm conditions and may represent the “first flush” from that storm reaching Station 8.

TSS data were collected from July 1991 through May 1993 at locations south of the Stations 3/4 confluence through Station 8 as part of a monitoring program established through MIT (Solo-Gabriele, 1995). The TSS data observed during the TtNUS monitoring period were consistent with the earlier data. Both data sets show that TSS concentrations were consistently at about 5 mg/L throughout the length of the Aberjona River during baseflow conditions. During storm events increases in TSS concentrations were observed during both studies at Station 8. The increase in the TSS concentration during the rising limb of the hydrograph, however, was larger during the TtNUS monitoring period (recorded peak value of 1,980 mg/L) than during the monitoring period corresponding to the MIT study (recorded peak value of 90 mg/L). Regardless of the differences in the magnitude of the TSS peaks, the response after the peaks was very similar between both time periods. After the peak, TSS concentrations were observed in both studies to decline rapidly on the falling limb of the streamflow hydrograph. Also, Solo-Gabriele (1995) estimated that the overall TSS flux (baseflow and storm flow combined) at the outlet of the Aberjona River was between 30 and 70 kg/hr. The average measured TSS flux during the TtNUS monitoring period was 7 kg/hr during baseflow conditions and 470 kg/hr during storm flow conditions.

Evaluation of Arsenic Data

Baseflow data indicate that arsenic concentrations were generally higher in the northern portion of the Study Area (Table 4-5b) than in the southern portion. Low total arsenic concentrations (< 2 ug/L) occurred at Station 1 and at Stations 9 and 10. Total arsenic concentrations during baseflow conditions increased from Station 1 (< 2 ug/L) to Station 2 (20 ug/L) to Station 4 (37 ug/L). Concentrations observed at Station 3 were also elevated on average (19 ug/L). After Station 4, total arsenic concentrations sequentially decreased in the downstream direction. The highest total arsenic concentrations during baseflow occurred at Station 4 (37 ug/L on average),

which was characterized by concentrations that were more variable relative to other stations. Spikes in metals concentrations at Station 4 were associated with spikes in suspended sediment (TSS) concentrations, indicating that elevated levels of metals at this station were associated with the particulate phase.

The average total arsenic concentration observed during storm events was lower for Stations 3, 4, and 5 than during baseflow conditions. For all the other sampling stations, total arsenic concentrations were greatest during storm flow conditions (Table 4-5b). The increase in total arsenic for the other stations was due to an increase in suspended sediment transport during storm events, which resulted in an overall increase in the particulate arsenic concentration.

During baseflow conditions, arsenic flux increased from Station 1 to 2 to 4, then a decrease in the arsenic flux was noted in the area between the Stations 3/4 confluence and Station 5 (Table 4-5c). The arsenic flux observed at Station 4 was estimated at 6.7 g/hr and at Station 3 was estimated at 2.7 g/hr. The sum of these fluxes (9.4 g/hr) was almost a factor of two times higher than the flux observed at Station 5 (5.3 g/hr), suggesting that arsenic was depositing in the area upstream of Station 5. The Wells G&H wetland was one likely location, since this wetland is known to contain very high metals concentrations within its sediments. The flux remained between 4 and 6 g/hr from Station 5 through Station 8, located at the outlet of the watershed.

During storm flow conditions, arsenic fluxes increased considerably compared to baseflow conditions due to higher flows and TSS fluxes. Average fluxes during storm flow conditions ranged from 3.2 to 107 g/hr compared to a range of 0.2 to 5.3 g/hr under baseflow conditions. The arsenic flux was estimated at 68 g/hr at Station 2 as compared to 107 g/hr at Station 8 during storm flow. Measured arsenic fluxes were lower between these stations. When normalizing the total arsenic flux during storm flow conditions by the drainage area for each station, Station 2 contributed the largest flux (23 g/(hr/mi²). This relatively large contribution may have been due, in part, to the relatively large amount of water that was discharged by the corresponding drainage area (4.3 cfs/mi²) (Table 4-5d).

Arsenic data for surface water in the HBHA were available during the TtNUS monitoring period from the Industri-plex Site Remedial Trust (ISRT – See Section 4.5.2), which collected separate samples for arsenic analysis from nine stations in the HBHA. The location of two ISRT stations coincided with the location of the TtNUS Station 2 and 4. Although samples were not split

between TtNUS and ISRT, samples were collected during the same general time periods between August 2000 and March 2004. Average dissolved arsenic concentrations between the ISRT and TtNUS studies were within 20 percent of each other. The average total arsenic concentration measured at TtNUS Station 2 was within 40 percent of the average value measured by ISRT. The average total arsenic concentration measured at TtNUS Station 4 was approximately two times higher than the average value measured by ISRT.

General trends observed in the arsenic data were also consistent with the data collected through the MIT monitoring network approximately 10 years earlier (Solo-Gabriele, 1995). The location of two of the MIT stations coincided with the location of two TtNUS stations (Stations 6 and 8). Overall, the highest concentrations of arsenic from both monitoring networks were observed within the northern sections of the watershed, and the measured arsenic concentrations at Stations 6 and 8 were within the same order of magnitude. The dissolved arsenic concentrations observed during the MIT monitoring period at Station 6 were between 3 and 7 ug/L. This was consistent with the average observed by TtNUS (2.7 ug/L during baseflow and 4 ug/L during storm flow). Total arsenic observed through the MIT monitoring network was on the order of 8 ug/L. Again this was consistent with the averages observed by TtNUS (5 ug/L during baseflow and 17 ug/L during stormflow). At TtNUS Station 8, it appears that the particulate arsenic contribution may have increased between the two study periods. Dissolved arsenic concentrations were similar between each study (at 3 ug/L for the MIT study, and 1.5 to 2 ug/L for the TtNUS monitoring period). Particulate arsenic at Station 8 was at about 1 ug/L for the MIT study. For the TtNUS period, the inferred particulate concentration was on the order of 3 to 9 ug/L. As a result, it appears that the particulate flux of arsenic may have increased at Station 8 during the past 10 years. This may be associated with the higher storm event TSS peaks observed at this station during the more recent TtNUS study.

Evaluation of Other Metals (Iron, Chromium, Copper, Lead, and Mercury) Data

A strong association was generally observed between total iron and total arsenic concentrations, with both metals exhibiting similar patterns in fluctuations; both were highly correlated when data from a particular station or storm event were considered. One possible scenario for transport of arsenic is that during baseflow conditions, arsenic and iron entered the river through groundwater primarily within the northern reaches of the watershed. Once within

the river, some of the arsenic precipitated along with iron and deposited within the river bottom. This precipitate was then flushed out of the system during storm flows.

For Stations 1, 2, 6, 7, and 8, metals concentrations were typically higher during storm flow conditions than baseflow conditions (Table 4-5b). Metals concentrations at Station 4 were consistently higher during baseflow relative to storm flow. At Stations 3 and 5, concentrations of some metals were higher during baseflow (i.e. iron and arsenic) and others were higher during storm flow conditions. Overall, during baseflow conditions the highest concentrations of all metals were observed at Station 4. During storm flow conditions, iron concentrations were highest at Station 2 (as noted above for arsenic). For chromium, copper, and lead, the highest concentrations were observed at Stations 1, 6, and 8 during storm flow conditions. Typically mercury concentrations observed within the river were at or near detection limits. However, on occasion, mercury concentrations were observed above the detection limit at Station 4 during baseflow conditions and at Station 8 during storm flow conditions. Metals concentrations were typically the lowest at Stations 9 and 10 during baseflow and storm flow conditions. The low concentrations observed at Stations 9 and 10 were likely due to the deposition of suspended sediments within the Mystic Lakes.

Metal fluxes were typically higher during storm flow conditions relative to baseflow conditions. This increase was due to increases in flow and TSS fluxes during storm events. The largest drainage-area normalized chromium, copper, and lead fluxes were observed at Stations 1 and 8. The largest drainage-area normalized fluxes for these same metals were observed at Station 4 during baseflow conditions.

Overall Summary of the TtNUS Aberjona River Surface Water Investigation

During the TtNUS monitoring period, the primary concentrated source of arsenic to the Aberjona River entered the river within the HBHA. Some of the arsenic that was transported from the HBHA was deposited during baseflow conditions in the area between the Stations 3/4 confluence and Station 5, presumably within the Wells G & H wetland. During storm events, metal fluxes increased due to increased transport of particulate metals. Particulate metals transported during storms likely came from metals previously deposited within the HBHA and river system and metals deposited within drainage areas contributing to the river system.

Although the primary concentrated source of arsenic originates within the HBHA, areas upstream of the HBHA and the areas between Station 7 and 8 represented a concentrated source of copper, chromium, and lead during storm conditions. The source of the copper and lead during storms is currently unknown but was likely associated with urban runoff. Sources of chromium could also be associated with urban runoff or with discharges from the Olin Chemical Company site, located upstream of Halls Brook and connected by the East Drainage Ditch and New Boston Street Drainway.

Once the metals were transported through the Aberjona River system, they were likely diluted with inflows from the Mystic Lakes watershed and a portion of the metals was likely deposited within the Mystic Lakes. As a result, the surface waters of the Mystic Lakes were characterized by low metals concentrations relative to the concentrations observed within the upper reaches of the Aberjona River watershed.

4.5.1.2 Surface Water Contamination – Statistical Summary and Criteria Comparison

This section presents a comparison of the surface water data collected during the TtNUS surface water investigation with relevant surface water quality criteria developed for protection of aquatic organisms. This comparison is presented to identify whether contaminant concentrations observed in Study Area surface water exceed the applicable water quality standards and may pose a risk to aquatic organisms. The baseflow and storm flow data are compared with the following criteria for freshwater:

- Ambient Water Quality Criteria (AWQC) Criteria Maximum Concentration (CMC)(EPA, 2002a) – The CMC (or acute exposure criteria) is an estimate of the highest concentration of a substance in surface water that an aquatic community can be exposed to briefly without resulting in an unacceptable effect.
- AWQC Criteria Continuous Concentration (CCC)(EPA, 2002a) – The CCC (or chronic exposure criteria) is an estimate of the highest concentration of a substance in surface water that an aquatic community can be exposed to indefinitely without resulting in an unacceptable effect.

As presented in the AWQC document (EPA, 2002a), the AWQC criteria for metals are presented as dissolved metals. However, for purposes of comparison in this section, the AWQC are used as reference criteria for both dissolved and total metals. The AWQC criteria for seven metals (cadmium, chromium III, copper, lead, nickel, silver, and zinc) are hardness dependent. Equations presented in the AWQC document (EPA, 2002a) were used to adjust the criteria for site specific conditions. An average hardness value ($158 \text{ mg/L as CaCO}_3$) calculated from surface water samples collected throughout the MSGRP RI Study Area was used to adjust the AWQC criteria for hardness. The majority of hardness values observed were below 200 mg/L. Study area surface water data summary statistics and comparisons to reference criteria are presented in Tables 4-5e (baseflow) and 4-5f (storm flow). Complete analytical results for surface water are presented in Appendix 4D.

Surface Water Baseflow Samples – Metals Summary and AWQC Comparison

As shown in Table 4-5e, several metals were detected in the surface water baseflow samples collected from all the TtNUS monitoring stations. A total of 21 metals were detected in the baseflow samples. Most of the metals were detected in both filtered and unfiltered samples at most or all stations and most were detected in more than half of the samples at many stations. Two metals (aluminum and lead) were detected primarily in unfiltered samples and five (antimony, cadmium, mercury, selenium, thallium, and vanadium) were detected infrequently at only a few stations.

Three metals (iron, zinc, and cadmium) in the filtered baseflow samples exceeded the AWQC CCC criteria. Zinc also exceeded the CMC criteria. All exceedances occurred in samples from Stations 2, 3, 4, and 5. Iron exceeded the criteria in half the samples at Station 3 and less than 20 percent of the samples at Stations 2, 4 and 5. Zinc exceeded the CCC and CMC criteria in half the samples at Station 2 and one sample at Station 4 (the CCC and CMC criteria for zinc are the same). Cadmium exceeded the CCC criteria in one sample from Station 2.

Seven metals (iron, zinc, cadmium, aluminum, arsenic, copper, and lead) in the unfiltered baseflow samples exceeded the AWQC CCC criteria. Three (zinc, cadmium, and copper) also exceeded the CMC criteria. Only iron and zinc exceeded the criteria in at least half the samples at any station (iron CCC at Station 3 and zinc CCC and CMC at Station 2). All other exceedances of AWQC criteria occurred in less than one third of the samples at a station. Total

aluminum concentrations exceeded the AWQC CCC criteria in a small fraction of samples at Stations 1 through 8. Total lead concentrations exceeded the CCC criteria at Stations 4 through 8. The other five metals each exceeded the criteria at two or three stations.

Surface Water Storm Flow Samples – AWQC Comparison

As shown in Table 4-5f, several metals were detected in the surface water storm flow samples collected from all the TtNUS monitoring stations. A total of 23 metals were detected in the storm flow samples. Most of the metals were detected in both filtered and unfiltered samples at most or all stations and most were detected in more than half of the samples at many stations. Aluminum was detected primarily in unfiltered samples. Five metals (beryllium, cadmium, selenium, silver, and thallium) were detected infrequently at only a few stations; these were detected primarily in unfiltered samples.

Four metals (copper, iron, lead, and zinc) in the filtered storm flow samples exceeded the AWQC CCC criteria. Copper and zinc also exceeded the CMC criteria. The exceedances occurred in samples from Stations 2, 4, 6, 7, and 8. The criteria exceedances were infrequent: each metal exceeded the CCC criteria in one to three stations, in fewer than one third of the samples at a station. Dissolved copper concentrations exceeded the CCC criteria in samples from Stations 6 through 8. Dissolved iron and zinc concentrations exceeded the CCC criteria in samples from Stations 2 and 4. Lead exceeded the CCC criteria only at Station 8. Copper and zinc also exceeded the AWQC CMC criteria at two stations each.

Eleven metals (copper, iron, lead, zinc, aluminum, arsenic, cadmium, chromium, mercury, nickel, and selenium) in the unfiltered storm flow samples exceeded the AWQC CCC criteria. All of these except nickel and selenium also exceeded the CMC criteria in samples from at least one station. Most of the exceedances occurred in Stations 1 through 8, but cadmium exceeded the criteria in one sample from Station 9. AWQC exceedances of all eleven metals occurred at Station 8. Four metals (copper, iron, lead, and aluminum) exceeded the CCC criteria in at least half the samples from any station. Total concentrations of iron exceeded the criteria in most samples from Stations 1 through 8. Lead exceeded criteria in more than half the samples from Stations 1, 2, and 5 through 8, and some samples from Station 4. Aluminum and copper each exceeded CCC criteria at least five of the first eight stations. The remaining metals exceeded criteria only sporadically at one to three stations.

4.5.2 Surface Water Contamination and Contaminant Transport in the Halls Brook Holding Area under Base Flow and Storm Flow Conditions

As described in Sections 2.1.5.3 and 2.1.5.4, two surface water monitoring investigations of the Halls Brook Holding Area were conducted on behalf of the ISRT in 2000 and 2001. The *Final GSIP SOW Surface Water Monitoring Investigation* was conducted by Arcadis for the ISRT between September 2000 and August 2001 to monitor the surface water quality as it leaves the HBHA Pond and the downstream wetlands. The investigation consisted of 12 monthly sampling events at two locations: the HBHA Pond outlet (HBHA-1) and the outlet of the HBHA wetlands at Mishawum Road (HBHA-2). The samples were collected under baseflow conditions and analyzed for total metals (arsenic, chromium, lead, iron, and mercury), dissolved metals (arsenic, chromium and lead), benzene, toluene, and total suspended solids. See Section 2.1.5.3 and Table 2-3 for details of the investigation. Sample locations are shown on Figure 2-5a.

The *Final GSIP SOW Downgradient Transport Investigation* was conducted by Roux, on behalf of the ISRT, between March 2000 and June 2001. The objective of the surface water component of the downgradient transport investigation was to perform a hydraulic evaluation of the HBHA. To accomplish this objective, nine automated surface water monitoring stations (SW-1-IP through SW-9-IP) were established within the HBHA at all point-source inflows and outflows to the HBHA Pond and wetlands, and various monitoring tasks were conducted at these stations. The investigation included collection of surface water quality data and flow measurements during four baseflow periods and seven storm events. Baseflow samples were collected at the three perennial stations: SW-1-IP (Halls Brook discharge into HBHA pond), SW-4-IP (HBHA pond outlet) and SW-9-IP (HBHA outlet at Mishawum Road). Storm flow samples were collected at these stations as well as the six ephemeral stations located at storm drainway discharges into HBHA.

Samples from stations SW-4-IP (same location as station HBHA-1) and SW-9-IP (same location as station HBHA-2) were analyzed for total (unfiltered) TAL metals, dissolved arsenic, TCL SVOCs, cyclohexanone (a non-TCL SVOC), and TSS. Samples from the remaining stations were analyzed for total (unfiltered) arsenic, chromium, lead, and mercury; dissolved (filtered) arsenic; selected SVOCs (bis(2-ethylhexyl)phthalate, diethylphthalate, PAHs, 4-methylphenol, and cyclohexanone); and TSS. See Section 2.1.5.4 and Table 2-3 for details of the investigation.

The data collected during these HBHA surface water monitoring investigations were reviewed and evaluated in the *Draft Evaluation of Flow, Suspended Sediment, and Heavy Metals in the Aberjona River* (TtNUS, January 2005), as described in Section 4.5.1. The following sections present a comparison of the surface water data collected during the HBHA investigations with relevant surface water quality criteria developed for protection of aquatic organisms. The comparison criteria used (and described) in Section 4.5.1.2 to evaluate the data from the TtNUS surface water monitoring investigation are used to evaluate the HBHA investigation data:

- Ambient Water Quality Criteria (AWQC) Criteria Maximum Concentration (CMC)(EPA, 2002a)
- AWQC Criteria Continuous Concentration (CCC)(EPA, 2002a)

The hardness dependent criteria (cadmium, chromium III, copper, lead, nickel, silver, and zinc) are calculated as described in Section 4.5.1.2. As stated there, although the AWQC criteria for metals are presented as dissolved metals, for purposes of comparison in this section the AWQC are used as reference criteria for both dissolved and total metals. Halls Brook Holding Area surface water data summary statistics and comparisons to reference criteria are presented in Tables 4-5g (baseflow) and 4-5h (storm flow). Complete analytical results for surface water are presented in Appendix 4D.

4.5.2.1 Baseflow Conditions

Baseflow samples were collected at three stations: SW-1-IP, SW-4-IP/HBHA-1, and SW-9-IP/HBHA-2. These stations coincide with TtNUS stations SW-01-TT, SW-02-TT, and SW-04-TT respectively. As shown in Table 4-5g, 18 metals were detected in the unfiltered surface water baseflow samples collected from the ISRT HBHA monitoring stations. Dissolved arsenic, chromium, and lead were also detected (they were the only dissolved metals included in the analyses).

No dissolved (filtered) metals exceeded the AWQC criteria in the HBHA baseflow samples. Six metals (aluminum, cadmium, copper, iron, lead, and zinc) in the unfiltered baseflow samples exceeded the AWQC CCC criteria. Copper and zinc concentrations also exceeded the AWQC CMC criteria. Most of the exceedances occurred in the samples from HBHA outflow stations

SW-4-IP/HBHA-1 and SW-9-IP/HBHA-2. All six metals exceeded the CCC criteria at these stations, whereas only lead exceeded the CCC criteria in SW-1-IP, the outlet of Halls Brook into the HBHA. At Station SW-4-IP/HBHA-1, all of the metals except aluminum exceeded the CCC criteria in more than half of the samples. At Station SW-9-IP/HBHA-2 iron and zinc exceeded CCC criteria in more than half of the samples.

As shown in Table 4-5g, nine SVOCs and one VOC (toluene) were detected at relatively low concentrations in the surface water baseflow samples collected from the ISRT HBHA monitoring stations. SVOC analysis was conducted in samples from SW-1-IP, SW-4-IP and SW-9-IP during three baseflow sampling events. VOC analysis was conducted in samples collected from HBHA-1 and HBHA-2 during 12 baseflow sampling events. Most of the SVOCs were detected during only one sampling event. Cyclohexane, fluoranthene, phenol, and pyrene were each detected at more than one station. Toluene was detected in 2 of 12 samples collected at station HBHA-1.

4.5.2.2 Storm Flow Conditions

Storm flow samples were collected at nine stations: SW-1-IP through SW-9-IP. As shown in Table 4-5h, 18 metals were detected in the unfiltered surface water storm flow samples collected from the ISRT HBHA monitoring stations. Dissolved arsenic was also detected (it was the only dissolved metal included in the analyses).

No dissolved (filtered) metals exceeded the AWQC criteria in the HBHA storm flow samples. Five metals (aluminum, cadmium, iron, zinc, and lead) in the unfiltered storm flow samples exceeded the AWQC CCC criteria. Zinc concentrations also exceeded the AWQC CMC criterion, which is the same as the CCC criterion for that metal. Only samples from perennial stations SW-4-IP and SW-9-IP were analyzed for the complete list of TAL metals; unfiltered samples from the other stations were analyzed only for arsenic, chromium, lead, and mercury. Concentrations of four metals (aluminum, cadmium, iron, and zinc) in samples from SW-4-IP exceeded the CCC criteria in at least half of the samples. Concentrations of all these except cadmium in SW-9-IP exceeded the criteria; only iron exceeded the criteria in more than half the samples. Lead concentrations exceeded the CCC criteria in samples from SW-1-IP and ephemeral stations SW-2-IP and SW-5-IP through SW-8-IP. At Stations SW-5-, SW-7-IP, and SW-8-IP lead exceeded the CCC criteria in more than half of the samples.

4.5.3 Surface Water Contamination in “Snap-Shot” Samples from Throughout RI Study Area

Two investigations were conducted on behalf of the ISRT and EPA which included collecting grab samples of surface water along with other associated media at sample locations in pond, river, and wetland habitats in the Study Area.

As described in Section 2.1.5.5, Menzie Cura collected surface water samples in June 1999 on behalf of the ISRT during the Final GSIP SOW Ecological Risk Investigation. The investigation included sampling and analysis of surface water and other media at 13 sampling stations (MC-01 through MC-13): eight in the HBHA Ponds and wetlands and the Aberjona River downstream of the HBHA and five at reference stations. At stations where the water depth was less than 3 feet, a single mid-depth sample was collected. At stations where the depth was greater than 3 feet (observed at three stations), two samples were collected: one from 1 foot below the water surface and one from 1 foot above the bottom. All samples were analyzed for dissolved metals, total metals, arsenic speciation, PCBs, pesticides, VOCs, SVOCs, TSS, hardness, and several additional water quality parameters. Sampling stations are shown on Figures 2-5a, 2-5b, and 2-6. A sampling summary is presented on Table 2-4.

As described in Section 2.2.1.1 FW conducted a comprehensive field investigation in July through September 1995 on behalf of EPA for the Wells G&H Aberjona River Study. The investigation included sampling and analysis of surface water from 17 stations in the Southern Study Area and five reference stations. Surface water samples were analyzed for VOCs, SVOCs, pesticides/PCBs, total metals, TSS, and a suite of additional water quality parameters. Surface water sampling stations (SW-01-01-FW through SW-27-01-FW, excluding Stations 17 and 19 through 22) are shown on Figures 2-5a through 2-5f. Table 2-6 presents the analytical method references and sample summary for all sample stations.

The primary use of the surface water data collected during these investigations is to aid in the assessment of ecological and human health impacts from site-related contaminants in Study Area surface waters. The data were used along with the surface water data from the investigations described in the previous sections to evaluate the effects of contaminants in surface water. Their co-location with samples of associated media provide a means to evaluate the relationships among contaminants in surface water, sediment, and biota. Because the surface water samples were collected from each location during a single sampling event they

provide a “snap-shot” image of contamination that was present at the time. But due to the ephemeral nature of surface water, the snap shot samples do not provide a comprehensive view of the nature and extent of contamination that exists in the surface waters over time.

The following sections present a brief comparison of the surface water data collected during these investigations with relevant surface water quality criteria developed for protection of aquatic organisms. See the HHRA (Section 6 and Appendix 6) and ERA (Section 7 and Appendix 7) for additional discussion of the data. The comparison criteria used to evaluate the Study Area baseflow and storm flow surface water data (describe fully in Section 4.5.1.2) are also used here to evaluate the “snap-shot” surface water data:

- Ambient Water Quality Criteria (AWQC) Criteria Maximum Concentration (CMC)(EPA, 2002a)
- AWQC Criteria Continuous Concentration (CCC)(EPA, 2002a)

Although the AWQC criteria for metals are presented as dissolved metals, for purposes of comparison in this section the AWQC are used as reference criteria for both dissolved and total metals. Surface water snap-shot data summary statistics and comparisons to reference criteria are presented in Tables 4-5i. Complete analytical results for surface water are presented in Appendix 4D.

4.5.3.1 Metals – Snap-Shot Surface Water

The following sections present a comparison of the surface water snap-shot metals data with relevant surface water quality criteria developed for protection of aquatic organisms. The results for the study area reference stations are presented first, followed by the results for the study area stations.

Reference Stations Snap-Shot Surface Water – Metals

Surface water snap-shot samples were collected at 12 reference stations (Figures 2-5e and 2-5f) and analyzed for metals. All 12 samples were analyzed for total (unfiltered) metals; only six were analyzed for dissolved (filtered) metals. As shown in Table 4-5i, 18 metals were

detected in the unfiltered surface water samples and eight (dissolved) metals were detected in the filtered samples.

Iron was the only dissolved metal that exceeded the AWQC criteria in the reference station snap-shot samples; it slightly exceeded the AWQC CCC criteria in one of six samples. No dissolved metals exceeded the AWQC CMC criteria.

Four metals (aluminum, copper, iron, and lead) in the unfiltered reference station samples exceeded the AWQC CCC criteria. Aluminum and iron both exceeded the criteria in more than half the samples. Aluminum also exceeded the AWQC CMC criteria in one of 12 samples.

Study Area Snap-Shot Surface Water – Metals

Twenty nine surface water snap-shot samples were collected at study area stations (Figures 2-5a through 2-5e) and analyzed for metals. All 29 samples were analyzed for total (unfiltered) metals; only ten were analyzed for dissolved (filtered) metals. The dissolved metals samples were all collected from the MC-series samples in Reaches 0 (nine samples) and 1 (one sample). As shown in Table 4-5i, 20 metals were detected in the unfiltered surface water samples and ten (dissolved) metals were detected in the filtered samples.

Two dissolved metals (iron and zinc) exceeded the AWQC CCC criteria in the study area station snap-shot samples. Zinc exceeded both the AWQC CCC and CMC criteria in more than half of the samples (the two criteria are the same for zinc). Iron exceeded only the CCC criteria in 2 of 10 samples. Exceedances of AWQC criteria in the filtered samples were detected only in Reach 0. Only one other study area sample (MC-13 in Reach 1) was analyzed for dissolved metals; none of the dissolved metals detected in that sample exceeded AWQC criteria.

Nine metals (aluminum, arsenic, cadmium, chromium, copper, iron, lead, mercury, and zinc) in the unfiltered reference station samples exceeded the AWQC CCC criteria. Only iron exceeded the criteria in more than half the study area samples. Aluminum, arsenic, copper, and zinc also exceeded the AWQC CMC criteria. Zinc exceeded the criteria in 8 of 29 samples, the others exceeded the criteria in one sample each.

Exceedances of AWQC CCC criteria for metals in the unfiltered samples occurred in all study area reaches except Reach 5. The largest number of metals exceeding the AWQC CCC criteria occurred in Reaches 0 (six metals) and 1 (eight metals); these reaches also had the largest number of samples (nine – versus 4 or 1 in each of the other reaches). The other reaches all had three or four metals that exceeded AWQC CCC criteria in at least one sample. Three metals (aluminum, iron, and lead) exceeded AWQC CCC criteria in all study area reaches except Reach 5.

Exceedances of AWQC CMC criteria for metals in the unfiltered samples occurred only in Reaches 0 and 1. Arsenic and zinc exceeded CMC criteria in Reach 0. Aluminum, copper, and zinc exceeded CMC criteria in Reach 1.

4.5.3.1 Organic Compounds – Snap-Shot Surface Water

The following sections present a comparison of the surface water snap-shot organics data with relevant surface water quality criteria developed for protection of aquatic organisms. The results for the study area reference stations are presented first, followed by the results for the study area stations.

Reference Stations Snap-Shot Surface Water – Organic Compounds

Surface water snap-shot samples were collected at 12 reference stations (Figures 2-5e and 2-5f) and analyzed for VOCs, SVOCs, pesticides, and PCBs. As shown in Table 4-5i, no VOCs or PCBs, one SVOC, and 21 pesticides were detected. Only pesticides were detected at concentrations exceeding AWQC criteria.

Five pesticides (4,4'-DDT; alpha-chlordane; gamma-chlordane; heptachlor; heptachlor epoxide; and toxaphene) exceeded the AWQC CCC criteria in the reference station snap-shot samples. Each exceeded the criteria in only 1 of 12 samples, all at station MC-02. No organics were detected at concentrations exceeding AWQC CMC criteria.

Study Area Snap-Shot Surface Water – Organic Compounds

Surface water snap-shot samples were collected at 29 study area stations (Figures 2-5a through 2-5e) and analyzed for VOCs, SVOCs, pesticides, and PCBs. As shown in Table 4-5i, no PCBs, one VOC, nine VOCs, and five pesticides were detected. No organics were detected at concentrations exceeding AWQC criteria.

4.6 Fish Tissue Contamination

As described in Section 2, two fishery investigations were conducted by EPA and the ISRT to support the ecological and human health risk assessments for the study area. Fish and crayfish sampling were conducted jointly by the USFWS and FW on behalf of EPA between July and September 1995 (See Section 2.2.1.1) for the Aberjona River Study. A fishery survey and fish sampling was conducted jointly by the USFWS (representing EPA) and Menzie-Cura (representing ISRT) in June 1999 (See Section 2.1.5.5) for the Industri-plex Site.

In the 1995 investigation, fish and crayfish samples were collected from throughout the Southern Study Area and from two reference ponds. Fish samples were separated into four categories for analysis: small fish, large fish, large fish fillet, and large fish offal (carcass). The fish and crayfish samples were analyzed for metals, SVOCs, pesticides/PCBs, percent lipid, and percent moisture. Table 2-7 presents a sampling summary and the analytical method references for the 1995 fish investigation.

In the 1999 investigation, fish samples were collected from two ponds in the Northern Study Area and two reference ponds to obtain samples for tissue analysis and to assess the fish populations at the site and reference locations. Fish selected for analysis represented three different trophic levels: foraging species (pumpkinseed sunfish), bottom feeding species (brown bullhead and white sucker), and predatory species (largemouth bass) The forage fish were analyzed whole. The other (larger) fish were filleted and dissected, and fillet, liver, and offal samples were analyzed for each fish. All fish tissue samples were analyzed for metals. In addition, arsenic speciation analysis was performed on the fish fillet samples. Table 2-4 presents a sampling summary and the analytical method references for the 1999 fish investigation.

The following sections present a brief overview of the contamination detected in fish tissue collected from reference stations (Section 4.6.1) and from throughout the MSGRP RI Study Area (Section 4.6.2). For these evaluations, all fish sample types are combined together to provide an indication of the types of contaminants detected in all fish tissue. Refer to the HHRA (Section 6 and Appendix 6) and ERA (Section 7 and Appendix 7) for a detailed evaluation of the fish investigation data and the potential human health and ecological impacts of contaminants in fish tissue.

4.6.1 Reference Station Fish Tissue

Fish samples were collected from two ponds in the Northern Study Area (South Pond and Phillips Pond) two ponds in the Southern Study Area (Horn Pond and Wright Pond) that were judged to be representative of background conditions. The northern reference station ponds are shown on Figure 2-6 and the southern ponds are shown on Figure 2.7j. Reference station samples included 104 samples of various species and sizes of fish. Although samples were separated into different categories for analysis and evaluation as described above, they are combined into one data set to provide a general overview of the types of contaminants present in fish from reference station ponds.

All 104 reference station fish samples were analyzed for metals. In addition, 16 fish fillet samples from the northern ponds were analyzed for metals speciation and subsets of the samples from the southern ponds were analyzed for SVOCs (20 samples) and pesticides/PCBs(47 samples). Summary statistics for the reference station fish tissue data are presented in Table 4-6a. Complete analytical results are presented in Appendix 4E.

Reference Station Fish Tissue – Metals

As shown on Table 4-6a, 19 metals were detected in reference station fish tissue samples. Five of the metals (iron, mercury, potassium, selenium, and zinc) were detected in more than half of the samples. The rest of the metals were all detected in fewer than one third of the samples. Arsenic was detected in less than one quarter of all reference station fish samples sent for standard metals analysis. However, arsenic was detected at low concentrations (generally lower than the detection limits of the standard metals analysis) in all 16 fish fillet samples

analyzed for arsenic speciation. Organic arsenic typically comprised 85 to 90 percent of the total arsenic, with inorganic arsenic generally comprising 10 to 15 percent.

Reference Station Fish Tissue – Organic Compounds

As shown on Table 4-6a, one PAH was detected in 1 of 20 reference station fish samples analyzed for SVOCs. No other SVOCs were detected. Fourteen pesticides and two PCBs were detected in the 47 reference station fish samples analyzed for these compounds. One pesticide (4,4'-DDE) and one PCB (Aroclor 1260) were detected in nearly all the samples. Two other pesticides (4,4'-DDD and alpha-chlordane) were detected in more than half of the samples. The remaining compounds were all detected in fewer than one third of the samples.

4.6.2 MSGRP RI Study Area Fish Tissue

Fish samples were collected from two ponds in the Northern Study Area (HBHA Pond and HBHA Wetland Pond 3) and from the Aberjona River and associated ponds throughout the Southern Study Area. Study area samples included 205 samples of various species and sizes of fish. Nearly half the samples (95) were collected from Reach 0. Few fish samples were collected from Reaches 1 and 2 (7 samples each). The remaining reaches each had between 19 and 31 samples. Although the samples were separated into different categories for analysis and evaluation as described above in Section 4.6, they are combined into one data set to provide a general overview of the types of contaminants present in study area fish.

All 205 study area fish samples were analyzed for metals. A fraction of the samples were also analyzed for metals speciation (28 fish fillet samples from the Northern Study Area), SVOCs (31 samples from the Southern Study Area) and pesticides/PCBs (107 samples from the Southern Study Area). Summary statistics for the study area fish tissue data are presented in Table 4-6b. Complete analytical results are presented in Appendix 4E.

MSGRP RI Study Area Fish Tissue – Metals

As shown on Table 4-6b, 22 metals were detected in study area fish tissue samples. As in the reference samples, five of the metals (iron, mercury, potassium, selenium, and zinc) were detected in more than half of the study area samples. Four other metals (arsenic, cadmium,

chromium, and copper) were detected in 35 to 45 percent of the samples. The rest of the metals were all detected in fewer than one third of the samples. Arsenic was detected in all 44 fish filet samples analyzed for arsenic speciation. Organic arsenic comprised 80 to 99 percent of the total arsenic in these samples.

As shown on Table 4-6b, 13 to 18 metals were detected in samples from each reach, with the highest number of metals detected in Reaches 0 and 5. The detection frequency was lowest in the Reach 0 samples. Only four metals (arsenic, iron, selenium, and zinc) were detected in more than half of the samples in Reach 0. In all other reaches, 9 or 10 metals were detected in more than half of the samples. Differences in summary statistics between Reach 0 and the other reaches may be partly the result of different investigation methodology (i.e. different fish types and different sample contents) used in the investigations in the Northern and Southern Study Areas.

The metals most consistently detected in fish samples from Reaches 1 through 6 were cadmium, chromium, copper, iron, mercury, potassium, selenium, and zinc. Arsenic was detected in more than half of the samples only in reaches 0 and 1. It was detected in fewer than 30 percent of the samples in Reaches 2 through 6.

Most of the metals detected in every reach exceeded average background fish tissue concentrations in at least one sample. Average background concentrations were exceeded in more than half of the samples of arsenic (Reaches 0 and 1), chromium (Reaches 1 and 2), and zinc (Reaches 0, 1, 2, 4, 5, 6). Aluminum, lead, iron, and potassium also exceeded average background concentrations in one or two reaches each.

Arsenic was the only metal that exceeded the maximum background fish tissue concentrations in more than half the samples in an area (Reaches 0 and 1).

MSGRP RI Study Area Fish Tissue – Organic Compounds

Only samples collected from the Southern Study Area were analyzed for organic compounds. As shown on Table 4-6b, one SVOC (diethylphthalate) was detected in the study area fish samples. Both compounds were detected in only one sample each. No other SVOCs were detected. Eighteen pesticides and three PCBs were detected in the study area fish samples

analyzed for these compounds. One PCB (Aroclor-1260) was detected in all 107 samples. Three pesticides (4,4'-DDD; 4,4'-DDE; and gamma-chlordane) and one additional PCB (Aroclor-1254) were detected in more than 90 percent of the samples and five additional pesticides were detected in more than half of the samples.

Most of the pesticides and PCBs detected in the study area fish samples were present at concentrations exceeding average and maximum background fish tissue concentrations in at least one sample. Five pesticides (4,4'-DDD; 4,4'-DDT; alpha and gamma-chlordane; and dieldrin) one PCB (Aroclor-1254) exceeded average background concentrations in more than half of the study area fish samples. Exceedances of average and maximum background concentrations for pesticides and PCBs were identified in all reaches where they were analyzed (1 through 6)

4.7 Plant Tissue Contamination

As described in Section 2, aquatic plant samples were collected from reference station and study area wetlands during two investigations by the ISRT (See Section 2.1.5.5) and FW (See Section 2.2.1.1) to support the ERA. The investigation was conducted to evaluate potential impacts to birds and mammals from feeding on plants growing in contaminated sediment and/or surface water. Two types of vegetation were sampled for analysis of plant tissue: emergent vegetation was sampled to estimate potential impacts to aquatic mammals and submerged vegetation was sampled to estimate potential impacts to mammals and aquatic birds. This section presents a brief summary of the contamination detected in the plant tissue. Refer to the ERA (Section 7 and Appendix 7) for a detailed evaluation of the plant tissue data and the potential ecological impacts of contaminants in plant tissue.

Sampling of wetland vegetation was conducted by FW for EPA in August-September 1995 (Section 2.2.1.1) and by Menzie Cura for the ISRT in June 1999 (See Section 2.1.5.5). Emergent species samples were collected during both investigations from a total of nine study area sampling locations in Reaches 0 and 1 and three reference locations. Emergent species collected included cattail, common reed, burreed, pondweed, pickerelweed, arrowhead, and spike rush. Emergent plant samples collected during the 1995 study were composites consisting of roots, stems, and leaves from several species. (Only the basal portions of stems and leaves on tall emergents such as cattails and reeds were included.) Emergent samples

collected during the 1999 study were composites consisting of only the roots or lower stem from five cattail plants.

Submergent species samples were collected only during the 1999 investigation from three study area sample locations and two study areas. Submergent species collected included pondweed, coontail, water chestnut, yellow water lily, and an unidentified grass-like plant (referred to as plant C). Each submergent sample was a composite of roots or lower stems from five plants of the same species collected from the area of the sampling station. At some stations samples of more than one submergent species were collected.

The plant tissue samples collected during the 1995 FW study were analyzed for metals, SVOCs, and pesticides/PCBs. The samples collected in the 1999 ISRT study were analyzed only for metals. See Tables 2-4 and 2-8 for investigation details.

The plant tissue data from study area samples are presented below in Section 4.7.1 and the study area plant tissue data are presented in Section 4.7.2. The MSGRP RI Study Area data were compared to the study area data to assess whether contaminant concentrations detected in site media are elevated relative to background conditions in the study area.

4.7.1 Reference Station Plant Tissue

Aquatic plant samples were collected from three reference locations that were judged to be representative of background conditions. The reference areas were located in areas representative of study area habitats, but not likely to be impacted by site- or other-contaminant sources. Study areas are shown on Figures 2-6 (MC-02 and MC-03) and Figure 2.7i (SD-23-FW).

Reference station samples included seven composite samples of emergent plant species and eight composite samples of submergent plant species. All reference station samples were analyzed for metals. In addition, one of the emergent species samples was also analyzed for SVOCs and pesticides/PCBs. Summary statistics for the reference station plant tissue data are presented in Table 4-7a. Complete analytical results are presented in Appendix 4F.

Reference Station Plant Tissue – Metals

As shown on Table 4-7a, 17 metals were detected in the reference station emergent species plant tissue samples. Three of the metals (iron, manganese, and zinc) were detected in all eight samples, four others (aluminum, arsenic, lead, and vanadium) were detected in more than half of the samples. Four minerals (calcium, magnesium, potassium, and sodium) were also detected in the one sample in which it was analyzed. The highest concentrations of metals were generally detected in the root portion of the emergent plants.

As shown on Table 4-7a, nine metals were detected in the reference station submergent species plant tissue samples. All nine metals were detected in at least half of the samples. Four of the metals (arsenic, iron, manganese, and zinc) were detected in all eight samples. The highest concentrations of metals were generally detected in the stem portion of the submergent plants.

Concentrations of most metals were similar in the emergent and submergent plant samples collected from the reference stations.

Reference Station Plant Tissue – Organic Compounds

As shown on Table 4-7a, five pesticides were detected in the reference station emergent species plant tissue sample. No SVOCs or PCBs were detected in the reference sample analyzed for organic compounds. Submergent plant tissue samples were not analyzed for organic compounds.

4.7.2 MSGRP RI Study Area Plant Tissue

Aquatic plant samples were collected from nine sample locations in the HBHA and the Wells G&H 38-acre wetland where sediment samples were also collected. Sample locations are shown on Figures 2-7a (MC-08, MC-09 and MC-11) and Figure 2-7b (SD-18-01-FW, SD-18-02-FW, SD-20-01-FW, SD-20-02-FW, SD-21-01-FW, and SD-21-02-FW).

Plant samples included 18 composite samples of emergent plant species and 16 composite samples of submergent plant species. All study area samples were analyzed for metals. In

addition, six of the emergent species samples were also analyzed for SVOCs and pesticides/PCBs. Summary statistics for the study area plant tissue data are presented in Table 4-7b. Complete analytical results are presented in Appendix 4F.

MSGRP Study Area Plant Tissue – Metals

As shown on Table 4-7b, 20 metals were detected in the study area emergent species plant tissue samples. Four of the metals (arsenic, iron, manganese, and zinc) were detected in all 18 samples, five others (aluminum, chromium, copper, lead, and vanadium) were detected in more than half of the 18 samples. All nine of these metals except iron were present at concentrations greater than average background concentrations in at least half of the samples; five (arsenic, cadmium, chromium, copper, zinc) also exceeded maximum background concentrations in at least half of the samples. Four minerals (calcium, magnesium, potassium, and sodium) were detected in all six study area samples in which they were analyzed; they were generally present at concentrations similar to those in the background samples.

As shown on Table 4-7b, ten metals were detected in the study area submergent species plant tissue samples. Seven of the metals were detected in at least half of the 16 samples. Five (aluminum, arsenic, iron, manganese, and zinc) were detected in 15 or 16 samples. Arsenic chromium and zinc were present at concentrations greater than average background concentrations in at least half of the samples; arsenic and zinc concentrations also exceeded maximum background concentrations in at least half of the samples.

Concentrations of metals in the study area emergent plant samples were generally higher than in the submergent plant tissue and concentrations in samples from the root portion of the emergent plants were generally higher than in the samples from the stem portion of the plants. Concentrations of most metals in emergent plant tissue were highest in root tissue from HBHA sample station MC-08. However, the maximum concentration of some metals, including chromium, was detected in samples from the Wells G&H 38-acre wetland.

Most of the metals detected in study area emergent plant samples were present at concentrations exceeding average and maximum background emergent plant tissue concentrations in at least one sample. Several metals exceeded background concentrations in more than half the samples.

Five of the metals detected in study area submergent plant samples were present at concentrations exceeding average and/or background submergent plant tissue concentrations in at least one sample. Only two metals (arsenic and zinc) exceeded average background concentrations in more than half the samples; they also exceeded maximum background concentrations in more than half the samples.

MSGRP RI Study Area Plant Tissue – Organic Compounds

As shown on Table 4-7b, eight PAHs were detected in study area emergent species plant tissue samples. Most of the compounds were detected in at least half of the six samples. None of these compounds

As shown on Table 4-7b, 11 pesticides and one PCB were detected in study area emergent species plant tissue samples. Three of the pesticides (4,4-DDE; alpha chlordane; and gamma chlordane) and the PCB (Aroclor 1260) were detected in all six samples. Alpha chlordane concentrations exceeded the maximum background concentration in all six samples. Gamma chlordane and Aroclor 1260 were not detected in the background samples.

Submergent plant tissue samples were not analyzed for organic compounds.

4.8 Benthic Invertebrate Tissue Contamination

As described in Section 2, benthic invertebrates were collected from reference station and MSGRP RI Study Area sediment during two investigations by the ISRT (See Section 2.1.5.5) and TtNUS (See Section 2.2.2.1) to support the ERA. The samples were collected for three purposes: community evaluation, toxicity testing, and chemical analysis of tissue. These three elements are considered in the ERA, along with sediment contaminant data, to evaluate the toxicity impacts of sediment contamination on the biological population in the study area. This section presents a brief summary of the contamination detected in the invertebrate tissue. Refer to the ERA (Section 7 and Appendix 7) for a detailed evaluation of the tissue data as well as the results of toxicity testing and benthic community analysis.

Benthic invertebrates were collected for tissue analysis only during the Final GSIP SOW Ecological Risk Investigation conducted by Menzie Cura for the ISRT in 1999 (Section 2.1.5.5).

Invertebrate samples were collected for tissue analysis from four study areas and six MSGRP RI Study Area stations. Five of the MSGRP RI Study Area samples were collected from the HBHA ponds and wetlands, the sixth was collected from wetlands just south of Route 95 near Normac Road. See Figure 2-6 for ecological investigation sample locations.

Three different types of benthic invertebrates were collected for analysis: amphipods, chironomid larvae, and odonate nymphs. If enough biomass was collected, each type was analyzed separately, otherwise the different invertebrates were composited to produce enough biomass for analysis. Odonate nymphs were collected for analysis at only two stations. All composite samples consisted of only amphipods and chironomid larvae. All tissue samples were analyzed for metals. If sufficient mass remained, analysis was also conducted for PAHs. See Section 2.1.5.5 and Table 2-4 for investigation and analysis details.

The tissue data from study area samples are presented below in Section 4.8.1 and the study area invertebrate tissue data are presented in Section 4.8.2. The MSGRP RI Study Area samples were compared to the study area data to assess whether contaminant concentrations detected in site media are elevated relative to background conditions in the study area.

4.8.1 Reference Station Benthic Invertebrate Tissue

Benthic invertebrate tissue samples were collected from four reference stations that were judged to be representative of background conditions. The reference stations were located in areas representative of study area habitats, but not likely to be impacted by site- or other-contaminant sources. Reference stations are shown on Figure 2-6.

Reference station samples included four composite samples consisting of amphipods and chironomid larvae and three samples comprised only of odonate nymphs. All six reference station samples were analyzed for metals. Five of the samples were also analyzed for PAHs. Summary statistics for the study area invertebrate tissue data are presented in Table 4-8a. Complete analytical results are presented in Appendix 4G.

As shown on Table 4-8a, nine metals were detected in reference station invertebrate tissue samples. Five of the metals (aluminum, arsenic, iron, manganese, and zinc) were detected in all or most samples, the other four were each detected in only one or two samples.

As shown on Table 4-8a, 13 PAHs were detected in reference station invertebrate tissue samples. Four of the compounds (benzo(a)anthracene, chrysene, fluoranthene, and pyrene) were detected in at least three of the five samples; the remaining compounds were each detected in only one or two samples.

4.8.2 MSGRP RI Study Area Benthic Invertebrate Tissue

Benthic invertebrate tissue samples were collected from sediment at six MSGRP RI Study Area stations: five in the HBHA and one just south of Route 95. Sample stations are shown on Figure 2-6. The samples included four composite samples consisting of amphipods and chironomid larvae and two samples comprised only of chironomid larvae. All six samples were analyzed for both metals and PAHs. Summary statistics for the Study Area invertebrate tissue data are presented in Table 4-8b. Complete analytical results are presented in Appendix 4G.

As shown on Table 4-8b, 11 metals were detected in MSGRP RI Study Area invertebrate tissue samples (the nine detected in the reference samples plus two additional). Seven of the metals (aluminum, arsenic, chromium, copper, iron, manganese, and zinc) were detected in more than half of the samples. Three of these (arsenic, copper, and zinc) were present at concentrations higher than maximum background concentrations in more than half of the samples. Concentrations of two others (chromium and iron) were higher than average background concentrations in more than half of the samples.

As shown on Table 4-8a, 14 PAHs were detected in MSGRP RI Study Area invertebrate tissue samples (the 13 detected in the reference samples plus one additional). Eleven of the compounds were detected in more than half of the samples. Two compounds (fluoranthene and pyrene) were present at concentrations higher than maximum background concentrations in four of six samples. Concentrations of seven more compounds were higher than maximum background concentrations in three of six samples.

4.9 Sub-Slab Soil Gas

As described in Section 2.1.6, a sub-slab soil gas investigation was conducted by Roux on behalf of the ISRT in May and June 2004 to aid in the assessment of potential human health risks posed by VOC vapor intrusion into occupied buildings at the Industri-plex Site.

The soil gas sampling was conducted at seven buildings on and adjacent to the Industri-plex Site where there was the potential for indoor air to be impacted by migration of vapors from the shallow groundwater (see Figure 2-8). At six of the buildings, a soil gas sample was collected from immediately beneath the concrete building slab. At the seventh building (the Sacco Property located at 41 Atlantic Avenue), soil gas samples were collected from two locations approximately 4-feet below ground surface immediately outside the building. A duplicate sub-sample was collected at one property. All samples were analyzed for VOCs. See Section 2.1.6 for investigation details.

As shown in Table 4-9, 26 VOCs were detected in the sub-slab soil gas samples. Eleven of the VOCs, including benzene (5 of 8 samples) and toluene (7 of 8 samples), were detected in more than half of the samples. VOCs were detected in the soil gas samples from each of the seven properties sampled.

See the HHRA (Section 7 and Appendix 7) for a detailed discussion of the data and their use in the HHRA. Summary statistics for the sub-slab soil gas data are presented in Table 4-9. Complete analytical results are presented in Appendix 4H.

5.0 CONTAMINANT FATE AND TRANSPORT

The fate and transport of contaminants in environmental media are determined by a variety of factors. The physical and chemical properties of contaminants and the environmental media (i.e., soil, groundwater, surface water, and sediment) into which the contaminants are released are all factors that determine the eventual fate of these chemicals. For the Industri-plex MSGRP RI Study Area, the combination of Site-related contaminants, geologic and hydrogeologic conditions, and surface features influence how contaminants released to Industri-plex Site soils have migrated into other environmental media (i.e., the underlying groundwater, surface water bodies, and sediments) or have been transformed as the result of degradation processes. This section briefly describes the general fate and transport processes, discusses the chemicals found in onsite media, and presents an assessment of the potential fate and transport of those chemicals on and off the Industri-plex Site and within the overall MSGRP RI Study Area.

Section 5.1 summarizes the general fate and transport processes and contaminant properties that influence fate and transport. More detailed descriptions of fate and transport processes are available in a number of technical publications and documents. How these processes affect contaminant fate and transport through each type of media within the MSGRP RI Study Area (i.e. soils, groundwater, and surface water/sediments) are then discussed in Sections 5.2, 5.3, and 5.4. Finally, Section 5.5 presents the overall conceptual fate and transport model for each observed contaminant group (i.e. VOCs, SVOCs, and metals) within each reach of the MSGRP RI Study Area, starting from the Industri-plex Site to the Mystic Lakes.

As presented in Section 1.0, past operating practices at the Industri-plex Site have resulted in contaminant releases to the Site. Throughout the Industri-plex Site's operating history, large quantities of organic and inorganic chemicals, acids, and pesticides were brought to the Site, handled, and stored. These materials were used on the Site in the manufacture of chemicals to support the tanning industry, in the production of pesticides, and in other consumer products such as glue. Waste products were disposed on the Site in various locations in unlined piles, lagoons, and pits. Site development activities further re-distributed these wastes on Site. Some of which were consolidated into four hide piles and in areas along the BECO right-of-way along the southern boundary of the Site. As a result, chemicals were released to Site soils. Some of

these chemicals have remained adsorbed to soils while others have been mobilized into deeper soils, into groundwater, and into the adjacent wetlands, HBHA and Aberjona River.

South of the Industri-plex Site, the Aberjona River flows through urbanized sections of Woburn and Winchester. Both of these municipalities have an extensive industrial history, principally involving the tanning industry dating back into the early 1800s. Historically, waste products from these industries were reportedly discharged into the Aberjona River and may have contributed to the historical contamination of the river's water quality and sediments. As discussed in Section 2, these historical releases have been researched and documented by MIT (Aurillo, 1995) and EPA (Halliburton NUS, 1997 and TtNUS, 2003).

The evaluations of contaminant fate and transport presented in this section are based on available information for the MSGRP RI Study Area including; investigations of chemicals present in the environmental media; the physical state of contaminants in soil, groundwater, surface water, and sediment; general fate and transport mechanisms; and the interpretation of the geologic and hydrogeologic conditions. The fate and transport mechanisms at the Industri-plex Site and within the MSGRP RI Study Area are extremely complex due to the interactions between the soils, groundwater, surface water, and sediments.

5.1 General Fate and Transport Processes

The fate and transport processes of concern for the MSGRP RI Study Area are those that govern the migration of soil contaminants (once released or deposited) to other media (groundwater, surface water, sediments, and air). Once these contaminants have entered into other media, other fate and transport mechanisms occur that may cause further migration or chemical transformations. This generalized discussion of fate and transport processes is provided so that the observed Site-specific contamination conditions can be better characterized and understood.

5.1.1 General Fate and Transport Processes of Soil Contaminants

Once organic and inorganic chemicals are released to soils, a variety of processes occur that may cause them to become immobilized, degraded, or to be mobilized to another environmental medium. Some of these processes include:

- Volatilization – Chemicals having high Henry's Law coefficients or vapor pressures will readily enter (volatilize) into the ambient air rather than remaining adsorbed to the soil particles. Once in the atmosphere, the chemicals may undergo further transport through additional processes such as advection, diffusion, or dispersion. The chemicals may also be transformed through chemical processes such as hydrolysis or photolysis.
- Leaching – Chemicals may be transported downward through the soil strata by water from precipitation or by liquids that infiltrate through the soils. The leaching of chemicals from soils and their subsequent mobilization are controlled by soil properties (i.e., adsorptive capacity, organic carbon content, clay content, or specific surface area) and by chemical properties (i.e., solubility, ability to partition to other phases).
- Runoff/Erosion – In situations where the chemicals remain adsorbed (bound) to soil particles because of soil or chemical characteristics, chemicals may still be mobilized from one contaminated area to another or to other uncontaminated environmental media. Contaminants can be conveyed over land by runoff that occurs during precipitation events (solubilized in rainwater or adsorbed to suspended particles), or through the erosion of contaminated soils.

5.1.2 General Fate and Transport Processes of Groundwater Contaminants

Organic and inorganic contaminants introduced at the ground surface through spills, discharges, and disposal practices have contaminated the groundwater within the MSGRP RI Study Area, specifically at the Industri-plex Site.

5.1.2.1 Physical Phases of Contaminants in Groundwater

Contaminants occur in groundwater in two principal physical phases: dissolved (disassociated molecules) and suspended solids (adsorbed to mobile particles). These physical phases dictate how contaminants are transported and changed within the aquifer and are summarized as follows:

Dissolved Phase - Dissolved aqueous phase organic and inorganic contaminants generally migrate in the direction of groundwater flow. Three processes transport dissolved-phase

contaminants: advection, mechanical dispersion, and molecular diffusion. These processes are presented in Section 5.1.3 in more detail. In addition, dissolved contaminants may interact with both the aquifer matrix and other groundwater constituents during transport. A variety of chemical, physical, and biological interactions can significantly retard or accelerate the rate of dissolved contaminant transport, or transform the contaminants into other chemicals or states.

Suspended Solid Phase - Metals and some organic compounds can migrate through aquifers as suspended solids, either in insoluble form or adsorbed to small particles. Research has demonstrated that, depending on the nature of the geologic formation, clay- and silt-sized particles in the colloidal range (0.001 micron to 1.0 micron) can migrate through an aquifer with the groundwater, and that certain organic compounds and metals can be retained on the colloid surfaces through surface charge attractions. Special groundwater sampling techniques have been used during the sampling of monitoring wells for this RI to obtain samples that include the colloids that would be transported with the groundwater, but exclude the particulates that would be introduced from the disturbance in the well caused by sampling. Several of the contaminants identified in the MSGRP RI Study Area, particularly the metals, most commonly occur in the dissolved phase, however, they can also occur in the particulate phase. Therefore, some of the contamination detected in the groundwater may be moving as suspended solids. The sampling methods employed however, do not delineate between the fraction that is dissolved and the fraction that may be attributed to colloidal movement.

For chemicals that have migrated downward into groundwater from the unsaturated soils through precipitation infiltration and leaching, additional natural processes come into play that affect the contaminants' fate and transport in the subsurface environment. Table 5-1 presents a matrix table of processes that may influence contaminant migration, the corresponding geologic and hydrogeologic characteristics that affect transport, and the chemical's physical and chemical properties that cause chemical interactions that could increase or retard migration.

5.1.2.2 General Transport and Transformation Processes of Contaminants in Groundwater

The major contaminant transport processes in groundwater typically consist of advection, dispersion, and molecular diffusion. Advection, the bulk movement of groundwater, is the principal mechanism for contaminant transport in an aquifer. Dispersion and diffusion are secondary processes for dissolved contaminant transport. Two transformation processes are

important in determining the ultimate fate of contaminants in groundwater: degradation and retardation. Each of the transport and transformation processes is briefly described below:

Advection – Advection is the dominant transport process in groundwater. It consists of the movement of dissolved and suspended phase contaminants or of particles within a natural fluid flow. Advection is the flow of a fluid in response to a gradient, such as pressure or hydrostatic, and contaminant transport results from the entrainment of the chemicals in a flow field. Advection of dissolved contaminants in an isotropic, homogenous, porous medium results in the contaminants being transported with and migrating at the same velocity as groundwater. Flow directions for advective transport can be determined from the groundwater contours for the Site.

Mechanical Dispersion - Mechanical dispersion is a mixing process that results from velocity variations within bodies of moving fluids. In groundwater environments variable velocity regimes are caused by irregularities in the aquifer media, and these irregularities exist at a variety of scales. For example, velocity variations at the microscopic scale arise from: 1) fluids moving faster through the centers of pores than along the edges; 2) fluids moving faster through large pore spaces than through narrow ones; and 3) some fluid particles following more tortuous flow paths than others as they travel around individual soil particles. At the macroscopic scale, velocity variations result from the presence of layers or lenses of materials having different hydraulic conductivities.

The mixing due to dispersion increases as aquifer heterogeneity increases, and it results in the dilution of a solute body as contaminated water mixes with uncontaminated water along the margins of a plume. Dispersion also results in the spreading of a contaminant plume over a larger area (both parallel and perpendicular to the direction of flow) than would be expected by advection alone. The effects of dispersion were incorporated into the contaminant transport models presented later in Section 5.3 via the longitudinal and transverse dispersivity parameters.

Molecular Diffusion - Molecular diffusion is movement in response to a concentration gradient. Dissolved contaminants will move from areas of high concentration to areas of low concentration within an aquifer even if the groundwater is not moving, because the process is driven by the random thermal motion of the contaminant molecules. Diffusive transport is a slow process compared to the more rapid processes of advection and dispersion. Diffusion is

typically the dominant transport mechanism only in low-permeability hydrogeologic systems, and it is not incorporated into the models used for this investigation because of the more permeable nature of the Site/MSGRP RI Study Area geology.

Preferential Flow – In aquifer systems, preferential pathways for groundwater flow occur due to heterogeneities in the subsurface soils and the bedrock matrix. Geologic materials that are more permeable (soils or bedrock fractures) allow the preferential flow of groundwater and chemicals through those geologic units.

Biological Degradation – The degradation of organic groundwater contaminants can occur by biotic (biological) and abiotic (non-biological) means. In biological degradation (biodegradation), microorganisms utilize available chemicals to obtain needed energy and nutrients through reduction-oxidation (redox) reactions. This involves the transfer of electrons from the food/energy source (the contaminant) to an electron acceptor, such as oxygen. Depending on the microorganisms and contaminants present, biodegradation can occur in groundwater under either aerobic or anaerobic conditions.

Under aerobic conditions, carbon (as organic compounds, whether naturally occurring or anthropogenic) is oxidized by microorganisms to provide a net energy gain that is necessary for growth and reproduction. Typically, low-molecular weight and soluble organic compounds are readily degraded by bacteria and fungi (Hemond, 1994). Aromatic hydrocarbons (i.e., BTEX compounds) are used by microorganisms as a primary substrate (electron donor). Dissolved oxygen is used as the primary electron acceptor (chemical reduction) by the aerobic microorganisms. Once the oxygen is depleted, anaerobic microorganisms (bacteria) use other available electron acceptors (e.g. nitrates, sulfates, carbon dioxide, ferric iron) causing those chemicals to be transformed to a reduced state. For example, nitrate is converted to nitrogen gas or ammonia, arsenic(V) to arsenic(III), ferric iron (Fe [III]) to ferrous iron (Fe[II]), manganese(IV) to manganese (II), sulfate to sulfide ion, chlorinated solvents to compounds with one less chlorine atom, and carbon dioxide to carbon monoxide to methane.

Also, through the degradation processes, chemicals that were not originally present at the Site may be produced. In some cases, these daughter products may be more toxic than the original compounds released at a site. For example, aquifer microorganisms can reductively

de-chlorinate trichloroethene to the less chlorinated daughter products such as dichloroethene or further to the more toxic, vinyl chloride.

Abiotic Degradation - Mechanisms of abiotic degradation include hydrolysis, photolysis, chemical oxidation, and chemical reduction. Hydrolysis is the process where a chemical molecule and a water molecule are both split and recombine to form new chemicals. Chemical oxidation consists of the loss of electrons by an organic compound or a metal ion. Photolysis is the chemical process by which molecules are broken down into smaller units through the absorption of light, typically yielding electrons. Chemical reductions are the chemical reactions whereby an organic compound or a metal gains electrons, thus subsurface contaminants may be degraded or transformed by these naturally-occurring abiotic processes. The dominance or effectiveness of these transformation processes is governed by factors such as temperature, pH, solubility, etc.

Retardation - Most groundwater contaminants react to some extent with the aquifer's solid surfaces. Consequently, their transport is affected not only by the processes of advection, dispersion, and diffusion, but also by surface reactions. If the contaminants react via adsorption/desorption with mineral surfaces or the oxyhydroxide or organic coatings on these surfaces, the rate of contaminant transport will be slower than the rate of groundwater flow. The extent to which the movement of a plume is retarded relative to the rate of groundwater flow depends on the solute's propensity to sorb to the aquifer's surfaces. The propensity to sorb is governed by many factors including the chemical character of the solute, the composition of the aquifer's solid surfaces, and the groundwater chemistry.

Single parameter distribution coefficients (K_d s) are often used to quantify the tendency for a solute to sorb to media surfaces. K_d s are based on a linear model of adsorption – i.e. it is assumed that the mass of solute sorbed increases linearly as its dissolved concentration increases. K_d theory works best for nonionic organic solutes such as chlorinated solvents and fuel hydrocarbons (Stumm and Morgan, 1996). These compounds sorb primarily to organic coatings on mineral surfaces. A number of studies have shown that nonionic organic solute K_d s can be estimated from the fraction of organic carbon in the soil and the octanol-water partition coefficient (K_{ow}) of the solute. K_d theory also works for ionic solutes that: 1) sorb weakly; 2) participate in few reactions; 3) are present in low concentrations; and 4) move through geochemically homogeneous groundwater systems (Bethke and Brady, 2000).

However, the K_d construct is too simple to accurately represent the sorptive behavior of heavy metals, because they tend to sorb strongly and react to form various species and complexes. Nevertheless, the K_d approach is generally applied almost universally to models of heavy metal transport, because the site-specific data needed for more robust and realistic sorption models are rarely available (Davis and Kent, 1990; Koretsky, 2000).

5.1.3 General Transport Processes of Contaminants in Sediment and Surface Water

The transport processes of contaminants in sediment and surface water are generally the same as those observed controlling contaminant migration through soils and groundwater. These processes, as discussed in the previous sections, include advection, mechanical dispersion, molecular diffusion, biological degradation, abiotic degradation, and retardation. However, some processes maybe more dominant or significant in surface water than groundwater such as mechanical dispersion, mixing, or photolysis.

Once entrained in the water column, sediments are subject to the transport mechanisms governing the surface water. In addition to (gravity) advection, as observed in groundwater transport processes, surface waters are also subject to wind-drive advection. Wind may create surface currents or drift in one direction which in turn causes return currents at deeper levels.

Sediments may precipitate or settle out depending on the suspended solid particle mass and flow velocities of the surface water. The rate of settling depends upon the grain size of sands and upon the mineralogy and chemistry of the suspended solid particle. Once part of the sediment bed, the settled particle can be eroded and transported when the shear stress exerted on the bed by waves or flows, acting either alone or together, exceeds a critical minimum shear value. The critical shear stress also varies according to sediment size, mineralogy and chemistry. If sediment is deposited in locations where the critical shear stress is not exceeded, or is exceeded only infrequently, then the sediment will slowly consolidate, increasing in both density and strength. As bed density increases, so the stress threshold for erosion increases, and the sediment deposit becomes more stable and less likely to be eroded by natural forces.

Temperature or chemical stratification within deeper bodies of water may create layers, effectively dividing the water column into distinct zones that prevent mixing. The result may create an anoxic environment at the hypolimnion layer (the colder lower layer of a body of water

separated from upper warmer layer [epilimnion] by a thermocline). However, at least twice per year, larger quiescent surface water bodies such as lakes and ponds, typically undergo “turnover”.

Water is most dense (heaviest) at 39°F. As water temperature near the surface increases or decreases due to seasonal climate changes, the water becomes increasingly more or less dense (i.e. less dense as the temperature increases or more dense as the temperature decreases, approaching 39° F). During the late fall or early winter, as the surface waters become colder and more dense, they sink toward the bottom of the lake displacing warmer bottom water to the surface. This continues until the water temperature at all depths reaches approximately 39° F. Because there is very little difference in density at this stage, the waters are easily mixed by the wind. The sinking action and mixing of the water by the wind results in the exchange of surface and bottom waters and is called "turnover." Similarly, in spring, as the surface ice melts, the surface water warms to approximately 39°F, becoming heavier than the water immediately below it, and therefore sinks (MDNR, 2004). The downward movement of surface water forces water in the deeper parts of the lake upward. The resulting circulation of water is called “spring turnover”.

Sediments, both in the suspended and depositional state, can undergo chemical transformations through molecular diffusion and abiotic and biotic degradation similar to saturated soils. In addition, the geochemical conditions of the surface water can also influence the state that the chemical exists, either in an insoluble state or in a dissolved state, or can cycle back and forth between the soluble and insoluble states.

In addition, certain contaminants may also migrate through surface water and sediments by contaminants that have accumulated in tissues of mobile biota by absorption/ingestion of contaminated sediments or contaminated surface water. Contaminants that have bio-magnified or bio-accumulated through the food chain can migrate offsite with the animal.

5.2 Contaminant Fate and Transport in MSGRP RI Study Area Soils

Past releases of solvents, organic compounds, and inorganic compounds to the ground surface at the Industri-plex Site have resulted in the presence of VOCs, SVOCs, and metals in soils at

the Site and within the MSGRP RI Study Area. Depending on a variety of factors, some of these chemicals have been mobilized and have migrated into other environmental media.

It is important to note that the initial remedial activities conducted at the Industri-plex Site addressed soil contamination and surface waste deposits (hide piles) with the design and construction of permeable and impermeable, multi-media, protective caps. The cap materials included low-permeable soils, asphalt pavement, and a high density polyethylene (HDPE) impermeable membrane (East Hide Pile and portions of the Atlantic Avenue drainway). (Also note that areas that were previously covered with asphalt pavement or concrete slabs were considered “equivalent cover” and did not require the multi-media cap. In all cases, contaminated soils, however, still remain below the caps, and in some locations below the water table, and as noted in Section 4.0 of this report, represent a contaminant source to deeper soils and groundwater.

Also, during the MSGRP RI, other areas adjacent to the Industri-plex Site boundaries that had not been investigated during the initial RI, were found to contain elevated concentrations of Site-related contaminants above the action levels that had been established for the soil remedy. These soils were not capped and could be a continuing contaminant source. These areas include the MBTA railroad right-of-way and a small parcel area between the southern Site boundary (BECO right-of-way) and the HBHA Pond. In addition, other soils within the MSGRP RI Study Area may have been contaminated by past releases from the Industri-plex Site. These areas include former Mishawum Lake bed sediments that were buried during property development work and flood plain deposition zones along the banks of the HBHA and Aberjona River. Also, refer to Section 2 for other potential source areas within the MSGRP RI Study Area.

The following discussions not only address soils located on the Industri-plex Site, but also include soils within the MSGRP RI Study Area that may have been impacted by Site-related contaminants.

5.2.1 VOCs Fate and Transport in MSGRP RI Study Area Soils

As discussed in previous sections, VOCs (i.e. benzene and toluene) were identified primarily in the groundwater “hot spot” areas at the Industri-plex Site. The general location of the plumes

were in the vicinity of the Atlantic Avenue/Commerce Way intersection (toluene) and a larger area extending from Atlantic Avenue to the BECO right-of-way (benzene). Three “hot spot” groundwater recovery locations were prescribed in the ROD; one roughly centered at each of the plumes’ core and one at the Site boundary, downgradient of the benzene plume, south of the BECO right-of-way.

The concentrations, location, and size of the “hot spot” areas plumes have remained fairly consistent and persistent over the years since they were first detected, which suggests that impacted soils are the primary continuing source. Several comprehensive investigations (soil, groundwater, soil gas, and geophysics) have been conducted by the ISRT to identify the source of the VOCs (e.g. buried drums, tanks, etc.), but failed to identify a concentrated source. The principal areas where VOCs were detected in subsurface soils were generally along Atlantic Avenue. Benzene and toluene were generally detected at relatively low concentrations compared with reference criteria in most samples. Only three samples exhibited an exceedance of reference criteria.

Benzene and toluene were also both detected in the three West Hide Pile soil samples. However, only one sample, collected immediately below the water table, exceeded the Region 9 PRG for benzene. Refer to Section 4 for more detailed discussions of the nature and extent of VOC contamination in soils.

The fate of the VOCs is dependent on the properties of the chemicals and the receiving environmental medium. VOCs could have been released at the surface through spills or discharges, or in the case of the West Hide Pile, buried as wastes were consolidated into the current hide pile configuration. In either case, the VOCs, assumed to have been originally released as liquids, would seep into the unsaturated soils and adsorb to soil particles, enter into the soil pore spaces, and eventually migrate vertically downwards under the influence of gravity until reaching groundwater. The fate and transport processes for VOCs in soils are discussed below.

Volatilization - VOCs at the ground surface would likely have volatilized to the ambient air over time because of their high vapor pressures and contact with the atmosphere. This is supported by the lack of analytical data showing the presence of VOCs in surface soils. For VOCs remaining in shallow soils (but below ground surface), the opportunities to volatilize are much

fewer. The MSGRP RI analytical results have identified VOCs present in soils extending from near the ground surface to the top of the water table at properties on Atlantic Avenue and at various locations within the East Central and West Hide Piles. As stated previously, while VOCs in soil have been detected, a concentrated source such as buried tanks or drums, have not been identified.

Leaching - VOCs in unsaturated soils act as continuing sources of contamination to groundwater. Precipitation infiltration permeates the unsaturated soils and gradually leaches VOCs from the soil particles and the humic materials. Depending on the properties of the specific VOCs (i.e., solubility, soil-water partitioning coefficients, etc.) and the materials they are adsorbed to, some of the VOCs partition to the infiltrated water and are conveyed downward to groundwater.

While the quantities and time frame when VOCs were released to the Site soils are unknown, the solubilities of these chemicals offer some insight to the persistence of some of the VOCs relative to others. The following table presents the solubilities for several VOCs detected at the Site.

Water Solubility of Various VOCs	
Aromatic Hydrocarbons	Solubility (mg/L)
Benzene	1,780
Toluene	505
o-xylene	178
Chlorinated Solvent	
Trichloroethylene (TCE)	1,100

*Approximate solubility at 20°C, source *Handbook of Environmental Data of Organic Chemicals, Second Edition*

Because the benzene and trichloroethylene are more soluble than toluene and xylenes, these VOCs will partition more readily by precipitation infiltration from soil particles, and will be transported with groundwater more easily. However, it is expected that all detected aromatic hydrocarbons adsorbed to unsaturated soils will gradually be leached by periodic precipitation

events or seasonal fluctuations in the water table. This assessment of VOC migration has been well demonstrated by the presence of VOCs (benzene and toluene) in groundwater at the Site.

Excavation/Human Activity – Soils can be mobilized during excavation by equipment, or digging by humans or animals. This may occur during on-site construction, renovation of the property, utility repairs, animal burrowing, etc. Subsurface contaminants may be conveyed into the air or to the surface allowing contact with humans. The most significant of these activities occurred during the late 1960s and early 1970s when at the Industri-plex Site, properties were being developed into an industrial park. Some of the Site wastes were consolidated into hide piles, redistributing some contaminants while exposing others during Site construction work and re-grading. Disturbance of Site soils would have also increased volatilization of contaminants from soils and increased the likeliness of dispersion through mixing and erosion by precipitation runoff and wind.

Biodegradation - Review of available data indicates that some limited biodegradation of organic compounds may be occurring at the Site and within the MSGRP RI Study Area, in particular, at the HBHA Pond, HBHA wetlands, and the West Hide Pile. As described in Section 5.1.2, the microorganisms metabolize carbon sources (such as petroleum hydrocarbons) and require electron acceptors to complete the oxidation-reduction reactions mediated by the microorganisms. The aromatic hydrocarbons (benzene and toluene) are likely being biodegraded by native soil microorganisms because the VOCs can be used as carbon sources. Because unsaturated soils have a low moisture content relative to saturated soils (i.e., overburden aquifer), the rate of degradation in the unsaturated soils is expected to be lower than would occur in groundwater because the microorganisms require dissolved-phase chemicals to metabolize the various organic compounds. While some evidence of biological activity is indicated by the presence of low concentrations of degradation compounds of TCE (i.e. dichloroethene (DCE) and cis-DCE) in shallow surface soils and in deeper subsurface soils in the former Mishawum Lake bed area, TCE has still been detected in groundwater indicating that the biodegradation of TCE is not complete.

In summary, review of analytical results and Site conditions indicate that the soils contaminated with VOCs are continuing sources of groundwater contamination at the Industri-plex Site and areas adjacent to the HBHA. The primary mechanism causing contaminant mobility is the periodic leaching by precipitation infiltration of VOCs adsorbed to soil particles or trapped in

pore spaces. While biodegradation of VOCs may be occurring in soils, the low presence of metabolic process by-products or degradation compounds indicates that this may be a very minimal process.

5.2.2 SVOCs Fate and Transport in MSGRP RI Study Area Soils

Soil samples analyzed for SVOCs under the MSGRP investigation were only collected in the area of the former Mishawum Lake bed. SVOCs (mostly PAHs) were detected sporadically in this area, generally at shallow and near surface depth intervals, and at low concentrations. The SVOC concentrations in most samples were low in comparison to reference concentrations. Benzo(a)pyrene was detected most frequently.

SVOCs (phthalates and PAHs) typically have low volatility, and are much less soluble than VOCs. Therefore, these SVOCs are likely to remain adsorbed to soil particles and are only gradually leached by precipitation infiltration. Phenolic compounds have higher water solubilities comparable to those of aromatic hydrocarbons and could be mobilized by leaching. However, phenolic compounds were not detected in Site soils. For SVOCs, biodegradation is possible, but is likely to be slow as SVOCs tend to be persistent in the environment.

SVOCs adsorbed to the soil particles present at the ground surface could be released to the ambient air through fugitive dust emissions. Wind erosion could cause contaminants adsorbed to soil particles to be transported offsite through advective air flow. Erosion of these soils could cause SVOCs to be deposited in sediments in drainage channels which flow to the HBHA Pond or to the Aberjona River.

In summary, while SVOCs are present in soils, they do not appear to be mobilizing to groundwater.

Previous investigations at the Industri-plex Site (i.e. original RI and GSIP investigations) did not evaluate the nature and extent of contamination of SVOCs at the Site. However, historical records indicate that the former chemical manufacturer at the Site used coal as a fuel source for the generation of heat and steam production. Combustion by-products typically associated with the burning of coal include SVOCs and PAHs. SVOCs/PAHs from these coal-related sources may have been present on surficial soils prior to construction of the soil remedy cap. During this

time, erosion of soils from the Industri-plex Site may have caused the transport of SVOCs/PAHs to sediments in the HBHA and downstream sediments of the Aberjona River. Although SVOCs/PAHs were detected in reference/background sediment samples as well as the HBHA and Aberjona River sediments downstream of the Industri-plex Site, the SVOCs detected the HBHA and other reaches of the Aberjona River were generally above (albeit within same order of magnitude) those observed at background locations. Also refer to Section 4 for more detailed comparisons of soil and sediment sample data to background data and reference criteria.

SVOCs/PAHs are generally considered to be ubiquitous in the environment, especially in urban areas as a result of anthropogenic activities. SVOCs/PAHs at the Site, if present, would have been capped during the soil remedy and there is not likely a concentrated source of SVOCs in the MSGRP RI Study Area.

5.2.3 Metals Fate and Transport in MSGRP RI Study Area Soils

As presented in Section 4, a variety of metals were detected in soils throughout the MSGRP RI Study Area. Metals that are adsorbed to soil particles can be mobilized through fugitive dust emissions, through erosion, or through leaching to groundwater. Fate and transport processes of metals-contaminated soils are discussed in the following subsections.

5.2.3.1 Soil to Air Migration

Soils present at the ground surface are subject to wind erosion that can convey the metals off site as contaminated particulates. As late as the 1960s and early 1970s, when plant operations and land development operations were active, wind erosion may have played a more significant role in contaminant transport than it does currently. Since the soil remedy was completed in 1998, the contaminated soils within the Industri-plex Site boundaries have remained capped. Unless the integrity of the cap is disturbed, the potential for fugitive dust emissions from this source is almost non-existent. However, contaminated soils detected outside of the Industri-plex Site boundaries are exposed and subject to the transport mechanisms presented in previous sections, specifically, lead-contaminated soils located within the MBTA railroad right-of-way and the small parcel of land between the HBHA Pond and the BECO right-of-way (i.e. sample area "A6"). These soils could be disturbed and subject to wind erosion.

In addition, soil samples collected in the MBTA right-of-way, under and adjacent to the railroad tracks, indicated elevated concentrations of lead (BATG, 2001). Soils directly underlying the tracks or along side of the tracks are generally covered by a stone ballast apron extending approximately 5-10 feet beyond the track. Although this helps to mitigate dust generated by moving trains, soils outside of the apron could still be impacted by train-induced wind and could migrate. Also, soils underlying the stone ballast could be brought to the surface from track maintenance and construction work and then be subject to the wind erosion as well.

Metals in soils along the banks and floodplain of the HBHA, Wells G&H wetlands, Cranberry Bog Conservation Area, and other locations along the Aberjona River could be subject to wind erosion although not likely, since soils are generally well moistened or saturated.

5.2.3.2 Soils to Sediments and Surface Water Migration

Similar to wind erosion, this transport process may have been a more significant contributor to contaminant transport during the period when plant operations were active and the area was undergoing more land development than it currently does since the Site was capped. In 1996, MIT conducted a study of the Mystic Lakes with the objective to date anthropogenic disturbances of sediments in the Aberjona watershed based on the chemical and geochemical analysis of the lake sediment core samples. This study showed that high concentrations of metals (i.e. arsenic and chromium) were detected in the deeper sediments, which correlated to the periods of peak industrial activity in the early 1900s. These concentrations seemed to decrease sharply in the upper sediment layers which correlated to the mid-1930s when much of the watershed became sewered. However, based on the sediment record, during the 1960s, elevated concentrations of these metals were again observed indicating that the metals had again been remobilized. This was a period when earth-moving activities were most intense at the Site (Spliethoff and Hemond, 1996).

During the MSGRP RI investigations, surface soil samples were also collected from areas that, based on topography, could currently be subject to erosion into the HBHA and Aberjona River or be subjected to periodic flooding. Samples collected along the banks of the HBHA, Wells G&H wetlands, Cranberry Bog Conservation Area, and other locations along the Aberjona River exhibited low to elevated concentrations of metals. Some of these soil constituents have been detected in the wetland sediments that abut these areas. During precipitation events,

contaminated soils can be conveyed by runoff into these wetland areas. Elevated total suspended solid (TSS) data for surface water samples collected during storm events indicate that suspended sediments are attributed in part to soil erosion when compared to TSS under baseflow conditions.

Once mobilized to a surface water, the suspended or settled sediment solid, or chemical sorbed to it, can undergo chemical transformations through molecular diffusion and abiotic and biotic degradation. Depending on the geochemical conditions of the surface water, these transformation processes can also influence the state that the chemical exists, either in an insoluble state or in a dissolved state, or can cycle back and forth between the soluble and insoluble states.

5.2.3.3 Soil to Groundwater Migration

The metals detected in Site soils were also detected in the underlying groundwater. The soils contain high concentrations of metals that were released by past Site activities. When subjected to precipitation, and based on the solubilities of the compounds and geochemical conditions, metals can be leached from the soils and conveyed into the underlying groundwater. In addition, some of the wastes deposited or consolidated into the hide piles and BECO right-of-way exists below the water table and is in direct, continuous contact with groundwater.

Metals may also be leached from the soils into groundwater through the seasonal rise and fall of the water table. Seasonal variations, as discussed in Section 3, are modest, with a 1 to 2-foot variance observed between spring, summer, and fall. However, more dramatic fluctuations may temporarily occur as a result of precipitation events. These fluctuations will occasionally cause more vadose zone soils to be saturated, and therefore subject to leaching.

5.3 Contaminant Fate and Transport in MSGRP RI Study Area Groundwater

For reasons stated in Sections 1 and 2, the groundwater investigations for the MSGRP RI are limited to the Northern Study Area only (i.e. north of I-95). The overall general groundwater flow in the Northern Study Area is in a southerly direction mimicking the topography of the buried bedrock valley. Groundwater tends to flow from the west to the southeast and from the east to the southwest towards the present course of the HBHA and the Aberjona River. Groundwater

elevations measured over the three water level rounds did not show significant seasonal fluctuations. The groundwater elevation tends to decrease to the south consistent with decreasing bedrock elevations to the south. In addition, groundwater elevations are greater on the west and east borders in comparison to the central portion of the MSGRP RI Study Area, which is also consistent with bedrock elevations.

While there is lateral groundwater discharge from the Site to the downgradient locations (HBHA Pond, HBHA wetlands, and Aberjona River), the groundwater plumes are capable of discharging into the bedrock aquifer. Interpretations of the available geologic and hydrogeologic information indicate that the overburden and bedrock aquifers are hydraulically connected, although the bedrock may be semi-confined. Available potentiometric level data indicate there is a slight net vertical upward or downward head difference between the overburden and bedrock aquifers, depending on location, which indicates that contaminated groundwater from the overburden aquifer could possibly migrate into the underlying bedrock.

Only one of four bedrock wells (OW-55) installed during the GSIP Phase 2 RI recharged sufficiently enough to enable the collection of a representative groundwater sample and the collection of representative water-level information over time. OW-55 was installed directly downgradient of the South Hide Pile. Vertical gradient data developed from the January, February, and March 1992 water level measuring rounds showed a consistent downward gradient between the bedrock and the basal unconsolidated deposits. Vertical gradients ranged between 0.0084 feet per foot (ft/ft) to 0.0334 ft/ft.

The other bedrock observation well clusters were installed downgradient of the West Hide Pile, near the western end of Atlantic Avenue and in the vicinity of the HBHA. Water levels within these pilot bedrock boreholes were monitored over a period of several weeks and revealed that groundwater recharge into these boreholes was extremely slow (i.e. less than 0.2 feet per day). Therefore groundwater samples could not be collected at these locations. This information indicates that the bedrock at these locations exhibits an extremely low hydraulic conductivity. Moreover, the bedrock at these locations also exhibits no appreciable secondary porosity. Due to this low hydraulic conductivity, the bedrock at these locations will not act as a flow pathway for constituent-impacted groundwater. In addition, during previous geologic investigations where bedrock samples were collected, the upper portion of the bedrock surface was found to be generally competent, unbroken, and contained joints that were calcite or sand-filled. These

features could typically impede the downward migration of contaminated groundwater into the bedrock as well.

During October 1991, an aquifer test was conducted using the E-5 well, which was located in close proximity to the GSIP well, B8-06, later installed in 2001. The pumping test results indicated a slight hydraulic connection between the bedrock and overburden aquifer. However, previous investigations indicate that there is a slight vertical upward gradient from the bedrock to the overburden aquifer at many monitoring locations in the vicinity of the HBHA (Golder, 1991c).

Due to the low hydraulic conductivity, the crystalline bedrock observed at three of the four bedrock observation well locations investigated during the GSIP Phase 2 investigations does not appear to be a pathway for the transport of organic and inorganic constituents, except at Observation Well OW-55. The downward gradients at this location however, may have been seasonal influenced and not sustained year round.

Once organic contaminants or metals enter into the groundwater, the primary transport mechanism is through advective flow, migrating with the general direction of groundwater. As discussed in Section 3, the shallow groundwater flow is in the direction of the Aberjona River and associated tributaries, while groundwater flow at greater depths is parallel to the main buried valley. More importantly, the shallow aquifer generally discharges to the HBHA Pond as well as other portions of the HBHA wetlands.

Diffusion and dispersion also can promote the migration of contaminants within the aquifers, while retardation processes can remove contaminants from the aqueous phase. The following subsections discuss the fate of each general class of contaminants (VOCs, SVOCs, and metals) that were investigated as part of this study.

5.3.1 VOCs Fate and Transport in MSGRP RI Study Area Groundwater

Once in the overburden aquifer, the dissolved phase VOCs will be transported via advective flow and discharge to the HBHA. As the VOCs migrate through the aquifer, their progression could be retarded by various processes such as sorption to soils or degradation by chemical or

biological means. Attenuation through dilution can also occur through mixing with less contaminated or uncontaminated groundwater, or through the influx of precipitation infiltration.

The most recent groundwater sampling indicates that benzene and toluene plumes are persistent although no evidence of non-aqueous phase liquid (NAPL) has been observed at any sample location. Specifically, the greatest concentrations of toluene appear to originate from an area at the Atlantic Avenue and Commerce Way intersection. The greatest concentrations of benzene appear to be in the Atlantic Avenue area and at the southern boundary of BECO ROW and a more localized plume at the West Hide Pile. These plumes are consistent with those reported in the 1983 Phase I RI and GSIP investigations conducted in 1990 to 1992.

A 1991 groundwater sample collected from the bedrock well OW-55 during the GSIP Phase 2 investigation exhibited concentrations of toluene at 1,800 ug/L and benzene at 1,800 ug/L, which were similar to those found in adjacent overburden wells, indicating some hydraulic connection between the overburden and bedrock aquifers. However, as stated previously, this connection may be localized or seasonally influenced.

Groundwater flow direction is to the southwest towards the HBHA. Plume maps indicate that little degradation or attenuation of benzene and toluene is occurring from the point of origin to the HBHA. However, concentrations of benzene and toluene are all generally non-detects beyond the southern limits of the HBHA Pond indicating the plume/groundwater is discharging to the HBHA Pond and adjacent wetlands and/or biodegradation of the organic contaminants is occurring. Samples collected at the groundwater/surface water interface within the HBHA Pond indicate that VOCs are discharging to surface water. However, surface water samples collected from upper portions of the HBHA Pond water column, as well as downstream locations, have not shown the presence of VOCs or have shown near-detection levels of VOCs further suggesting either dilution or attenuation through biological and chemical degradation processes.

In summary, VOCs in groundwater are mostly migrating through advective flow through the overburden aquifer. The combination of the overall trend of vertical upward gradients, the competent underlying bedrock surface, and the analytical data from the bedrock aquifer all indicate that contaminants may not be migrating downward from the overburden into the bedrock aquifer, except at localized areas and under certain seasonal conditions. Consistent with previous investigations, data from the MSGRP RI have shown that shallow overburden

groundwater is discharging to surface water bodies that border the Site, specifically the HBHA Pond and the downgradient HBHA wetlands. Groundwater flow at greater depths may be in part, flowing upward to the shallow groundwater and subsequently discharging the surface water bodies and wetlands, but generally continues to flow parallel to the main buried valley. Some biological degradation of VOCs in Site groundwater may be occurring, but is relatively insufficient based on the persistence of the plumes over time. The fate of VOCs in surface water is discussed further in Section 5.4.

5.3.2 SVOCs Fate and Transport in MSGRP RI Study Area Groundwater

SVOCs are generally insoluble or only slightly soluble in groundwater. SVOCs will likely adsorb to organic carbon present in the soils. The groundwater analytical data indicate that only 2 samples out of 102 exhibited SVOCs at concentrations that exceeded MADEP GW-3 standard.

As indicated in Section 5.3.1, the VOC plumes are discharging to the northern portion of the HBHA Pond. SVOC plumes, if present, would be expected to follow the same migration pathway. Review of the groundwater data shows that SVOCs were sporadically detected in only about 10 percent of the samples where SVOCs were analyzed. Where SVOCs were detected, samples exhibited very low concentrations (i.e. at less than 10 percent of the respective GW-3 value). In summary, these results suggest that the SVOCs are generally not very mobile in groundwater and their presence in sediment samples, if detected, is more likely attributed to erosion of surface soils and urban runoff.

5.3.3 Metals Fate and Transport in MSGRP RI Study Area Groundwater

Once metals are leached from the surficial soils to the subsurface and into the saturated soils (i.e. groundwater aquifer), the dissolved-phase metals will continue to migrate with groundwater flow. Other natural reactions may occur that retard or accelerate (i.e., sorption, reduction-oxidation reactions, etc.) the rate at which the metals migrate in the aquifer. Review of available information indicates that fate and transport processes at the Industri-plex Site have promoted the leaching and migration of some of the metals into groundwater.

The leaching of metals to groundwater is of particular concern when the groundwater quality is degraded to the extent that it poses potential threats to human health or to the environment. Based on the MADEP Groundwater Use and Value Determination for the Industri-plex Site, MADEP GW-3 standards were used to qualitatively identify metals in groundwater that may be of concern. Metals exceeding the MADEP GW-3 standards include: arsenic, cadmium, chromium, lead, mercury, nickel, and zinc. Of the metals detected in groundwater, these metals appear to be leaching from soils at sufficient quantities to cause exceedances. Unlike arsenic, which was detected in 303 of 469 groundwater samples (41 exceeded GW-3 standards) or zinc which was detected in 112 of 188 groundwater samples (12 exceeded MADEP GW-3 standards), mercury was only detected slightly above MADEP GW-3 standards in 1 sample out of 464, chromium in only 2 samples out of 464, cadmium in only 3 samples out of 191, nickel in only 6 samples out of 192, and lead only 11 samples out of 494. While all of these metals were detected in the Site soils, arsenic, chromium, mercury, and lead were likely attributable to past onsite releases based on the history of manufacturing processes and elevated concentrations of these metals at the Industri-plex Site.

Brief summaries of fate and transport mechanisms governing the metals detected with higher frequency in groundwater in excess of the GW-3 standards (arsenic, lead, and zinc) are presented below. Other metals (cadmium, chromium, mercury, and nickel) that had only a few exceedances of the GW-3 standards are considered isolated occurrences based on numerous groundwater samples collected under the GSIP and MSGRP RI investigations and are not considered representative of overall, Site-wide groundwater contamination problems.

As discussed in previous sections, as with VOCs, metals in groundwater are mostly migrating through advective flow through the overburden aquifer based on an evaluation of vertical gradients, bedrock geology, and groundwater data. Consistent with previous investigations, data from the MSGRP RI have shown that shallow overburden groundwater is discharging to surface water bodies that border the Site, specifically the HBHA Pond and the downgradient HBHA wetlands. Groundwater flow at greater depths may be in part, flowing upward to the shallow groundwater and subsequently discharging the surface water bodies and wetlands, but generally continues to flow parallel to the main buried valley.

5.3.3.1 Arsenic in Groundwater

Arsenic, a metalloid, has been detected in soils and groundwater at numerous locations throughout the Industri-plex Site and MSGRP RI Study Area, was identified as a primary COC during the original RI, and was one of the principal soil contaminant drivers requiring construction of the soil remedy. Although arsenic is considered to be naturally occurring, detections in Industri-plex Site soil samples consistently exceed MADEP background concentrations (20 mg/kg), which indicate its presence is the result of past releases. It was known to be used in the manufacturing of arsenical pesticides at the Site. As discussed in Section 4, arsenic and lead are widely distributed at the Industri-plex Site; 22 acres have arsenic and/or lead concentrations above 1000 parts per million (ppm) and 13 acres have concentrations greater than 100 ppm.

The arsenic exists in groundwater in two oxidation states; arsenite (As(III)) and arsenate (As(V)). As(III) is the most toxic of the two species and is more mobile. As(V) is the oxidized form and has a greater affinity for adsorption to other solids found in the aquifer, such as soil particles and other metal complexes.

Analytical results for Site groundwater samples indicate that concentrations of arsenic are greater than offsite or background concentrations. Review of the groundwater data indicates that arsenic was detected in 303 of the 464 groundwater samples collected and had an average concentration of 323 ug/L. The GW-3 standard for arsenic (2,000 ug/L) was exceeded in 53 groundwater samples with a maximum concentration of 24,700 ug/L. See Section 4 for discussion of analytical data.

Sample data show that arsenic in groundwater covers an extensive portion of the Industri-plex Site. As discussed in Section 3, groundwater flows from the Site in a southerly direction and discharges in the HBHA. Groundwater and sediment porewater sample data collected by EPA (Ford, 2004a) confirm that arsenic is discharging into the HBHA Pond. In addition, surface water sample data from Station 2 are reasonably representative of impacts to surface water from chemicals and metals that would be transported from the Site and discharging to surface water (HBHA Pond). The average concentration of dissolved arsenic observed in surface water samples collected at Station 2 during all baseflow sample events was approximately 20 ug/L, whereas the average concentration for Station 1, representing the Halls Brook inlet to the HBHA

Pond, was only 1.8 ug/L for the same time period. These groundwater and surface water data support the conclusion that arsenic is migrating through groundwater from the Site to the surface water of the HBHA Pond.

The processes and environmental factors that affect the mobility of arsenic in groundwater are complex and interrelated. These factors, which are discussed below, include pH, the reduction/oxidation (redox) state, the form of arsenic that is present in the environment, the presence of other chemicals that may be competing for electrons and binding sites to adhere to soil particles, and biological activity.

pH

The majority of groundwater samples where speciation analysis was performed indicated that arsenic was found either mainly as arsenious acid (H_3AsO_3), which has a valence state of +3 [referred to as As(III)], or as arsenic acid (H_3AsO_4), which has a valence state of +5 [referred to as As(V)]. In groundwater, where the pH is typically neutral, the arsenious acid, As(III) form is uncharged and arsenic acid As(V) is negatively charged (i.e. minus one or two protons). The negative charge on As(V) anion allows it to bind to the surface of rock or soil particles that are positively charged, thus removing it from the water. As the pH is raised, arsenic in groundwater tends to become increasingly more negatively charged as both the arsenic and arsenious acid lose H^+ ions, thus making it increasingly more likely to be attracted to positively charged binding sites and removed from groundwater.

However, the rock/soil binding sites are also affected by the increasing pH. As the pH goes up and the water becomes more basic the concentration of hydroxyl (OH^-) ions increase. The OH^- ions from the water compete with the arsenic for the ion exchange sites on the rock/soil surfaces. Once the binding sites have been neutralized by the OH^- ions, they are no longer available to the arsenic compounds, thus leaving the As(V) free in the water. So, as a general rule, as the pH increases, the arsenic concentrations in groundwater will tend to increase as well.

The arsenic concentration in groundwater can also be indirectly affected by the solubility of other metals and the reaction with variations in pH. If arsenic is bound to a mineral phase of another metal, such as an iron hydroxide, and the pH is sufficient to dissolve the mineral phase,

the result would be the release of anything bound to the mineral phase as well, thus indirectly increasing the arsenic concentration.

Redox

Another major factor that affects the form of arsenic in solution is the redox state of the environment. Under reducing conditions, the most stable soluble form of inorganic arsenic is as As(III)-arsenite (arsenious acid). Under oxidizing conditions, most of the arsenic remains in the As(V)-arsenate (arsenic acid) form where it is more stable. As previously mentioned, the mobility of arsenic may partly depend on its charge, so at a neutral pH, As(III) is more mobile than the dissociated forms of As(V). Because Site groundwater is generally neutral, this suggests that arsenic at the Site will likely be more mobile under reducing conditions since most of the arsenic will be present as As(III) and the pH conditions would further enhance mobilization.

Just as the pH of the system affects binding areas/sites on soil particles, the redox potential also affects the binding sites. Many of the binding sites for arsenic are made of oxidized iron or manganese species that form a coating on the soil particles or on the rock surface. Under reducing conditions, the metals on the soil surface can also be reduced, releasing them into solution. In this case, the binding sites are no longer available on the surface and the arsenic that may have been bound to that site, is also released back into solution (McRae, 2004).

Thus, two independent factors are likely to increase the mobility of arsenic under reducing conditions:

- reduction of As(V) to As(III), which is more soluble and thus, more mobile
- reduction of binding sites, releasing bound arsenic to a soluble form

Biological Activity

Organic forms of arsenic are typically rare in groundwater. There is little evidence that the arsenic-carbon bond can be formed in the environment by purely chemical means. Thus it is assumed that the synthesis of organo-arsenic compounds requires the involvement of a living organism and, presumably, the intervention of arsenic within the metabolic pathway of the cell.

Methylated arsenic was detected in some groundwater samples downgradient from the East Central Hide Pile during the GSIP Phase 2 investigations, but only in an area where sulfide was present above 1 mg/L in the groundwater.

Biological activity can affect arsenic mobility directly (by reducing the arsenic - As(V) to As(III)) or indirectly (by reducing the binding site). Bacteria can reduce Fe(III) on soil surfaces to Fe(II), which is then released into the water. Any arsenic that was attached to the Fe(III) binding site would also consequently be released.

Biological activities in groundwater are usually limited by the amount of organic carbon available to serve as a “food” source. There is a substantial organic carbon supply in Site groundwater as a result of the benzene and toluene plumes present on the Site. Organic carbon in the system acts as a reductant, lowering the redox potential and fueling the reduction of As(V) to As(III) and Fe(III) to Fe(II) (McRae, 2004). Again, both direct As(V) and indirect Fe(III) reducing reactions increase the mobility of arsenic in water.

Oxidation Reactions

In groundwater environments with an abundance of oxygen, oxidation reactions can also potentially release arsenic. In these situations, arsenic has to be associated with a reduced chemical, like sulfide. Many arsenic-containing minerals also contain sulfide. In the presence of oxygen, instead of using organic carbon as an energy source, bacteria can oxidize insoluble sulfides to sulfates. Once in the sulfate form, it becomes soluble in water and releases the arsenic. The arsenic that may be associated with sulfides located in buried waste deposits in Site soil, such as the hide piles and BECO right-of-way, and buried wetland soils and peat, such as the HBHA wetlands or former buried Mishawum Lake bed sediments may be contributing to arsenic in groundwater.

In summary, although the reactions are considered slow, arsenic can be mobilized into groundwater by the following processes:

1. In situations where the pH is high, arsenic may be released from surface binding sites that lose their positive charge. At neutral pH, As(III) is more mobile than the dissociated As(V) form.

2. Under reducing conditions, the most stable form of arsenic is As(III).
3. When organic carbon is present, it can serve as a bacteria food source that releases arsenic either by (a) directly reducing As(V) to As(III), which is more soluble, or (b) by reducing the element at the binding site which releases the arsenic that was attached there (for example, Fe(III) is converted to Fe(II) which dissolves in the water and releases the arsenic)
4. Arsenic bound within sulfide minerals can be released when the minerals are exposed to oxygen. This can happen when the water level drops and the minerals are exposed to air or if oxygenated groundwater comes into contact with buried arsenic/sulfide mineral complexes.

5.3.3.2 Lead in Groundwater

Recent MADEP guidance on background concentrations in natural soil suggests that lead is present at concentrations of 100 mg/kg (MADEP, 2002c). Lead is typically deposited into soils as particles through anthropogenic activities. The original RI, identified lead as a Site-related soil contaminant because of its relatively elevated concentrations in comparison with Site background sample lead levels and the history of use and storage at the Site relative to the manufacture of lead-arsenic pesticides. As with arsenic, lead is widely distributed throughout the Industri-plex Site and was another driver for constructing the protective soil remedy cap. Soils exceeding the remedial action level of 600 mg/kg were capped during construction of the soil remedy and remain onsite.

Once in the soils, the lead forms salts in the presence of humic acids. Lead will tend to bind to humic materials and to clayey soils because of ionic attraction. Formation of the lead salts is complex and is dependent on pH and organic carbon content. Depending on the soil minerals and humic matter present in the soils, the resultant salt may be soluble (as lead nitrate, lead chloride) or may only be slightly soluble (as lead sulfate, lead sulfide, lead oxide). If conditions become acidic, the lead salt will be leached from the soils. Once in the subsurface the lead can be re-adsorbed to clays or to organic matter and may be retarded from further migration.

Lead was detected in only 30 groundwater samples of the 464 samples analyzed and detected at concentrations ranging from 1.8 ug/L to 499 ug/L. The MADEP GW-3 standard for lead (30 ug/L) was exceeded in only 11 of the 464 groundwater samples. If the lead detected in groundwater was leached from Site soils and remained mobile, then lead would likely be detected more frequently as well as be evidenced in discharges to surface water. The average concentration of dissolved lead in the surface water samples collected at Station 2 (immediately downstream of the HBHA Pond) during all baseflow sample events, was less than 1 ug/L. This assessment supports the interpretation that the lead is generally not mobile in groundwater at the Site.

In summary, while lead has been detected in the Northern Study Area in concentrations exceeding the MADEP GW-3 standard at some locations, the available data indicate that the elevated lead levels are a localized condition or are possibly attributable to the presence of suspended solids in the groundwater samples. In addition, evaluation of downgradient groundwater data and surface water data indicates that the lead is not mobile.

5.3.3.3 Zinc in Groundwater

Zinc is present in Site soils at concentrations that exceed the MADEP background criterion for natural soil (100 mg/kg) and in the same general areas where arsenic and lead were found (see Figure 1-B). Although zinc in the soils is typically naturally occurring, the elevated concentrations suggest possible releases from previous Site activities. The presence of zinc has been noted in the groundwater underlying several portions of the Site and is generally coincident with the VOC plumes. Zinc was detected in 112 out of 188 groundwater samples analyzed with concentrations ranging from 2.4 ug/L to 31,700 ug/L and an average concentration of 729 ug/L. A total of 12 samples had zinc concentrations exceeding the MADEP GW-3 standard (900 ug/L).

Similar to arsenic, one possible reason for the zinc leaching and migration is the possible indirect effect of reducing conditions caused by the microbial degradation of organic carbon in soils. VOCs in groundwater, wetland peat deposits, and buried animal hides can be used as a carbon source. The microbes require electron acceptors to complete the oxidation-reduction reactions. After dissolved oxygen and nitrate are depleted, the microbes can use ferric iron, sulfate, and manganese as electron acceptors. The iron and manganese soil grain coatings

may also serve as binding sites for zinc. When chemically reduced, the iron and the manganese become soluble and consequently release the zinc.

Based on the available data, it appears that zinc in soils is being mobilized into groundwater at concentrations exceeding the state criterion at some locations. Ongoing subsurface geochemical processes appear to be causing the chemical reduction of iron and manganese to more soluble forms, thereby releasing the zinc. Although the frequency of exceedances is generally low, it is evidence of existing geochemical conditions that are promoting the mobilization of other metals.

5.3.3.4 Summary of Metals in Groundwater

Once in the aqueous phase, the metals will be conveyed through advection with the ambient groundwater flow. As groundwater migrates through the Site, some of the metals will undergo transformation processes that result in their return to an insoluble state. Reduction-oxidation, precipitation, and adsorption reactions can cause the dissolved phase ions to leave the aqueous phase. However, the concentration of dissolved metals, particularly arsenic, observed at fixed monitoring points, indicates that there is an insignificant level of attenuation occurring within the groundwater aquifer upgradient to the HBHA Pond and wetlands (Ford, 2004a) and as a result, some of these metals continue to migrate with groundwater and eventually discharge to the downgradient surface water bodies.

The presence of reduced groundwater conditions at the Industri-plex Site, that are favorable to continued metals migration, are likely being sustained by Site conditions that limit the amount of oxygen that is available in the shallow aquifer such as biodegradation of organic materials within the hide piles, BECO right-of-way, and wetland areas including the former buried peat and sediment deposits of Mishawum Lake, may also be depleting oxygen concentrations to levels that induce reducing conditions that favor metals migration. To a lesser degree, activities such as capping major portions of the Site with low-permeable materials, such as asphalt pavement, as part of the soil remedy and recent Site development that inhibit oxygen-rich precipitation from entering the aquifer may also contribute to the reduced conditions. However, based on recent groundwater data collected by EPA in 2004, following the 2001 completion of the RTC where more than 20 acres were paved and after completion of the site cap in 1996, there seemed to

be little noticeable changes to the geochemistry as compared to the groundwater sampling conducted by EPA in 1999.

Based on available analytical data, the metals in groundwater appear to discharge into the HBHA Pond and downgradient HBHA wetlands. Groundwater samples collected at multiple soil horizons, south of the HBHA wetlands at Mishawum Road generally exhibited non-detects or low detections of arsenic. This data, coupled with the hydrogeologic characteristics of the local aquifer, suggest that the arsenic plume is discharging to the HBHA system and/or is attenuating within the overburden aquifer downgradient of the HBHA system.

As dissolved metals are discharged via groundwater to the surface water and sediments, some of the metals will likely be adsorbed and removed from the aqueous phase because of interactions with organic materials, sulfides, or oxyhydroxides. These processes are discussed in more detail in the following sections.

5.4 Contaminant Fate and Transport in MSGRP RI Study Area Surface Water and Sediments

Once Site-related contaminants enter into the sediments and surface water (through erosion or groundwater discharge), other processes occur that affect the fate and transport of the organic chemicals and metals that have migrated from the Site.

5.4.1 VOCs Fate and Transport in MSGRP RI Study Area Surface Water and Sediments

VOCs conveyed by groundwater that discharge to HBHA sediments can accumulate in the sediments or be discharged directly to surface water. The VOCs in sediments may be biodegraded, partition to surface water, or remain bound to the organic matter present in stream sediments. VOCs that enter into surface water can volatilize into the ambient air where they are degraded by photolysis or hydrolysis; remain in surface water and undergo degradation processes such as biodegradation, hydrolysis, or reduction-oxidation reactions; or become attenuated through dilution, diffusion, and advection. A study conducted by MIT in 2000 concluded that biodegradation at the anoxic/oxic interface was the largest sink for benzene in the HBHA Pond as compared to other fate and transport processes (Wick, 2000).

Overall, the presence of VOCs in surface water and sediments is limited to the areas where VOC-contaminated groundwater discharges from the Site to surface water bodies such as the HBHA Pond (or possibly the South Pond adjacent to the West Hide Pile). VOCs (i.e. chlorinated solvents) detected in some sediment samples collected from the Wells G&H wetlands are likely associated with historical VOC contaminated groundwater sources within the Wells G&H Superfund Site. Elsewhere, there are no identifiable VOC impacts to the surface water or sediment. EPA conducted a more thorough investigation of the impacts of groundwater discharges to the HBHA Pond. Although the Site characterization effort for BTEX compounds under that investigation was insufficient for the purpose of delineating natural processes degrading these contaminants within the groundwater aquifer, the primary focus of that investigation was to assess if these compounds were being discharged into the HBHA Pond and could thus serve as a source of degradable carbon. In this respect, the continued discharge of BTEX compounds into the HBHA Pond, in part, drives the microbial processes that govern the redox chemistry of this system (Ford, 2004a).

5.4.2 SVOCs Fate and Transport in MSGRP RI Study Area Surface Water and Sediments

As described in Section 5.2.3, SVOCs are generally insoluble, are not very mobile, and are unlikely to migrate with groundwater to discharge to surface water. SVOCs detected in sediments are more likely attributed to soil erosion and urban runoff. There was a limited number of surface water samples analyzed for SVOCs during this investigation. Analytical results from these samples generally do not show the presence of SVOCs, or if present, were detected infrequently and at low concentrations. SVOCs in surface water have likely originated from erosion of contaminated surface soils and/or suspended solids contaminated with SVOCs associated with urban runoff. Once in surface water, SVOCs will associate with the sediment load and remain part of the bed load or, if sufficient flows are present, be re-suspended and transported further downstream.

5.4.3 Metals Fate and Transport in MSGRP RI Study Area Sediments

From 1999 to 2004, the EPA's Office of Research and Development conducted a study to assess subsurface arsenic contamination at the Industri-plex Superfund Site and the HBHA. This investigation is referred to as the Natural Attenuation Study (NAS). The purpose of this study was to 1) determine the migration mechanisms controlling arsenic transport at the Site

and in the MSGRP RI Northern Study Area; 2) provide an evaluation of the potential role of natural attenuation processes in mitigating arsenic transport from these areas, and 3) provide guidance for determination of reasonable, cost effective treatment technologies for a river/wetland in an urban watershed.

Three goals were addressed as part of the NAS investigation: 1) identification of the mobile form of arsenic in groundwater, 2) identification of the processes controlling arsenic uptake onto HBHA sediments, and 3) evaluation of the stability of arsenic associated with HBHA sediments. This information served as a basis for identifying the effectiveness of natural attenuation within the HBHA to mitigate down gradient migration of arsenic into the Aberjona River and for evaluation of potential remedial alternatives. The following discussions are excerpted from the Natural Attenuation Study Report prepared by EPA, which is included in its entirety as Appendix 2D.

The geochemical processes active within the groundwater aquifer underlying the Industri-plex Superfund Site and downgradient wetland area are similar to those observed at acid mine drainage sites. However, the groundwater underlying the Site is well buffered, preventing acidification within the aquifer and downgradient wetland. Oxidative dissolution of iron sulfides contained within waste materials deposited on the Site results in the continued production of dissolved iron and sulfate (Davis, 1994). The aquifer redox chemistry is sufficiently reducing to facilitate transport and discharge of iron as Fe^{2+} into the HBHA Pond. In oxic zones within the HBHA Pond, the oxidation of Fe^{2+} results in the precipitation of iron oxides that scavenge dissolved arsenic concurrently discharged from the groundwater aquifer.

Dissolved organic compounds (anthropogenic and natural) discharged into the HBHA Pond provide a readily degradable source of food for the microbial community within the sediments (Suarez and Rifai, 1999; Hertkorn et al., 2002, and references therein). This microbial activity within the deeper portions of the HBHA Pond results in the generation of an anoxic zone in which iron and sulfate reduction processes are active. This redox stratification appears to be maintained for most of the year due to the stability of the chemocline within the water column. The formation and maintenance of this chemocline is driven by the discharge of primarily low conductivity water at shallow depths (from Halls Brook) and high conductivity water at deeper depths (from Site-derived groundwater).

Source	1) Groundwater discharge 2) Sediment dissolution and re-suspension
Sink	1) sorption to sediment and subsequent burial 2) Sorption to suspended solids produced by iron oxidation/precipitation

The concentrations of solid phase arsenic observed in the sediments and the dissolved arsenic observed at the sediment-water interface indicate that there is incomplete removal onto sediments. Sediment solids rich in iron, sulfur and organic matter sequester a fraction of the total arsenic at the sediment-water interface. It is unclear which of these phases controls arsenic partitioning during burial. The remaining fraction of total arsenic at the sediment-water interface can be attributed to groundwater discharge and dissolution of iron oxides. Dissolved arsenic derived from these two inputs diffuses upward within the water column and is sequestered from solution during oxidation and precipitation of ferrous iron at the oxic-anoxic interface.

The production and dissolution of iron oxides behaves as a steady-state process as long as the chemical stratification is maintained within the water column. Thus, while dissolved arsenic concentrations can become high at depth, shallow water in the oxic zone remains low in dissolved arsenic. For example, dissolved iron and arsenic concentrations decline to near-zero values at a depth above the oxic-anoxic interface. A turbidity maximum is also observed at this interface, which can be attributed, in part, to the observed maximum in particulate iron. The particulate iron is dominated by iron oxides, which serve as a sink for arsenic. As the iron oxides settle back to the sediment-water interface, they begin to dissolve via reductive mechanisms causing the reduction in turbidity and the release of arsenic.

The general geochemical trends observed within the pond water column during sampling over a two-year period are depicted in the inset of Figure 5-1. The specific conductivity of Site-derived groundwater is approximately two to three times higher than that observed for the major surface water input (Halls Brook). As a result of the difference in density between surface and groundwater discharge, the pond remains stratified for most of the year. The specific conductivity of pond bottom water is consistent with groundwater conductivity measured immediately upgradient. Stratification (or formation of a chemocline) results in the maintenance

of anoxia within the deeper portion of the pond. Iron and sulfate reduction are active within the pond bottom waters and sediment pore water.

However, oxidation of ferrous iron from groundwater discharge occurs within the shallow portion of the water column as evidenced by the formation of reddish-orange iron oxides along the northern border of the pond. Deposition of iron oxides to the sediments in the anoxic zone occurs due to oxidation-precipitation of ferrous iron at the chemocline and erosion and re-deposition of iron oxides from shallow depths.

A major surface water runoff event occurred during the study. This resulted in turnover of most of the pond volume and depression of the chemocline at the north end of the pond. Over time, stratification of the pond was re-established. It was possible to monitor re-establishment of the chemocline within the north end of the pond via the monitoring well network. Evaluation of the specific conductivity depth profile over time within the multi-level tube cluster showed that a steady-state had been re-established with respect to surface and groundwater flow inputs within approximately 39 days. However, dissolved arsenic concentrations continued to increase within the water column beyond this time (total period of observation was 161 days). The dissolved arsenic concentrations observed in the deeper portion of the pond were significantly higher than observed concentrations in upgradient groundwater monitoring points at similar depth. The additional source of dissolved arsenic is due to the reductive dissolution of arsenic-laden iron oxides following deposition in the anoxic zone. These results indicate that the concentration of dissolved arsenic within the pond water column is dependent both on groundwater discharge and sediment dissolution. The major sources of input and removal of arsenic from the pond water column are depicted in Figure 5-2.

5.4.4 Metals Fate and Transport in MSGRP RI Study Area Surface Water

An extensive monitoring program was established throughout the watershed that included measurements of precipitation, streamflow, suspended sediment, and metals concentrations (dissolved and total), in addition to other physio-chemical parameters at 10 stations located along a 9-mile reach of the Aberjona River. The intensive monitoring period occurred during an 18-month time frame beginning May 2001 and ending October 2002.

Monitoring data showed that metals transport is highly impacted by total suspended solids (TSS) concentrations. Spikes in metals concentrations are associated with spikes in TSS. Monitoring data collected during baseflow conditions show that arsenic concentrations are higher within the northern portion of the MSGRP RI Study Area. This trend was also observed for the other metals evaluated (chromium, copper, iron, lead, and mercury). The highest concentrations for these metals were often observed at Station 4 (Mishawum Road). Average total arsenic concentration during baseflow conditions at Station 4 was 37 ug/L as compared to low concentrations (< 2 ug/L) observed at Station 1, the station located upstream of the HBHA. It is important to note that the arsenic concentrations at Station 4 were highly variable during baseflow conditions in comparison with the concentrations observed at other stations. Spikes in metals concentrations at this station were associated with spikes in suspended sediment concentrations indicating that elevated levels of metals at this station are associated with the particulate phase. The total metals typically decreased in concentration in the downstream direction past Station 4.

For all sampling stations (with the exception of Stations 3, 4, and 5), the total arsenic concentrations were greatest during storm flow conditions. The increase in total arsenic for these stations was due to an increase in suspended sediment transport during storm events which resulted in an overall increase in the particulate arsenic concentration. At Stations 3, 4, and 5, the total average arsenic concentrations decreased during storm events. Despite this observed decrease, the total arsenic concentration measured at these stations was still the highest observed among all stations during storm event conditions.

The average storm event concentrations for arsenic (total) at Stations 2 and 4 were 48 ug/L and 32 ug/L, respectively, whereas the average storm event concentration for arsenic at Station 8 was 13 ug/L, which is located at the outlet of the watershed. The corresponding baseflow concentrations were 20 ug/L, 37 ug/L, and 4.4 ug/L for Stations 2, 4, and 8, respectively.

Transport of total arsenic was enhanced at Station 4 during baseflow conditions whereas enhanced transport of total arsenic was observed for Station 8 during storm flow conditions. These results again emphasize the unique behavior of metals transport within the upper reaches of the watershed. Grab sample data collected during storm events also supports the hypothesis that the metals from Station 4 and upstream areas are translated through the river

and are observed at a later time at Station 8. This translation in the metal flux was apparent for two of the six storm events evaluated.

The reduction of metals observed during baseflow conditions at Station 5 and subsequent downstream stations indicate that deposition is occurring between stations. Sediment samples were collected at significant deposition areas along the HBHA and Aberjona River from the Industri-plex Site to the Mystic Lakes. These areas included the HBHA ponds and wetlands, the Wells G&H wetlands, the Cranberry Bog Conservation Area, Kraft Foods wetlands, Swanton Street Condominiums wetlands, Davidson Park, Winchester-Wedgemere train station wetlands, and the Mystic Lakes (Upper Forebay, Lower Forebay, Upper Mystic Lake, and Lower Mystic Lake). The distribution of arsenic and other metals show a clear pattern of metals transport from the northern part of the river and watershed originating at the Industri-plex Site, south to the Mystic Lakes with the greatest area of sediment deposition occurring at the Wells G&H wetland and areas north.

Surface water samples collected at the Mystic Lakes and at the Mystic River indicate that the lake system also serves as a sink for metals associated with TSS. Mystic Lake sediment core samples collected by MIT suggest a deposition pattern of metals that corresponds to periods of peak industrial activity at the Industri-plex Site as well as the leather tanning industry within the watershed (Spliethoff and Hemond, 1996). Although these activities have ceased, the metals in sediments continue to be deposited at steady levels above natural background concentrations, especially for arsenic. This present input of metals is likely the result of the mobilization of historically deposited materials from upstream deposition areas and from current inputs from groundwater discharges at the HBHA Pond.

5.5 Conceptual Fate and Transport Model for the MSGRP RI Study Area

Past storage, manufacture, and handling practices of numerous chemicals at the Industri-plex Site has resulted in the release of chemicals to Site soils of VOCs (aromatic hydrocarbons), SVOCs (including phthalates, phenols, and PAHs), and metals. Depending on the combination of Site-related contaminants, geologic and hydrogeologic conditions, and surface features, contaminants released to Site soils have migrated into other environmental media, specifically the underlying groundwater, adjacent surface water bodies, and sediments.

The following sections describe the conceptual site model for the fate and transport of contaminants through various impacted media throughout the MSGRP RI Study Area. Based on similar impacted media, similar COCs, similar fate and transport processes, and contaminant source areas, the conceptual model for contaminant fate and transport will be discussed by reach as follows:

FATE AND TRANSPORT MODEL AREA	IMPACTED MEDIA	CONTAMINANTS OF CONCERN
Reach 0 (Industri-plex Site and the HBHA)	Soils, Groundwater, Sediment, Surface water	VOCs, SVOCs, Metals
Reach 1 (38-acre Wells G&H wetland)	Sediment, Surface water, Groundwater	Metals
Reach 2 to Reach 6 (Cranberry Bog Conservation Area to the Mystic Lakes)	Sediment, Surface water	Metals

5.5.1 Conceptual Fate and Transport Model at Reach 0 (Industri-plex Site and the HBHA)

The changes to the northern portion of the Aberjona River watershed have contributed to contaminant migration over time from the northern reaches to the Mystic Lakes. Historically, the northern and southern branches of the Aberjona River merged and flowed through the Industri-plex Site. The Aberjona River then merged with Halls Brook and flowed into Mishawum Lake, a small manmade lake created as a result of a mill dam constructed at Mishawum Road. Portions of this lake would have served as the first depositional area for many of the contaminated sediments and industrial discharges that originated from the Industri-plex Site. Other downstream depositional areas would have included the Wells G&H wetland, the Cranberry Bog Conservation Area, and ultimately, the Mystic Lakes.

In the early 1970s, significant portions of Mishawum Lake were filled to create the HBHA, thus burying former lake-bed sediment deposits in some areas. The HBHA was constructed as a storm water retention area and control structure as part of an area-wide commercial development project. Based on a review of limited available information, the design effort was directed towards management of flows during storm conditions and not towards developing a viable wetland habitat. Further development of the Industri-plex Site involved excavations,

re-location and consolidation of Site wastes into hide piles, and the filling of wetlands. These disturbances likely caused the mobilization of Site contaminants into the waterways where they then migrated further downstream.

Other historical changes to the Aberjona River including course changes, culverting sections, wetland losses, and channelizing are discussed in more detail in Section 2. While these changes have influenced transport processes effects on Site-derived contaminants, none were as significant as the creation of the HBHA.

5.5.1.1 Fate and Transport of VOCs in Reach 0 (Industri-plex Site and the HBHA)

VOCs that adsorb to surficial soils at the Industri-plex Site are likely to have volatilized to the ambient air because of the chemicals' high vapor pressures. VOCs, released as liquids, can permeate into the subsurface, adsorb to soils, enter in soil pore spaces, or migrate under gravity into groundwater. VOCs in the subsurface may be degraded by naturally occurring bacteria that metabolize aromatic hydrocarbons.

VOCs in subsurface soils leach into groundwater through precipitation infiltration or migration. Review of analytical results and Site conditions indicates that these VOCs (comprising aromatic hydrocarbons [benzene and toluene]) are continually leaching into and contaminating the underlying overburden groundwater.

Two significant VOCs plumes have been delineated at the Site. A benzene plume is located near Atlantic Avenue and the BECO ROW and a toluene plume is associated with possible VOC-contaminated soils near Atlantic Avenue and Commerce Way intersection. These groundwater plumes continue to migrate in the general southwesterly direction, towards the HBHA. Despite several subsurface investigations involving soil samples, groundwater samples, soil gas samples, and geophysics investigations, a concentrated source has not been located.

VOC-contaminated groundwater migrates to and discharges to the HBHA Pond and HBHA wetlands. Under certain conditions where groundwater mounding occurs, VOCs could possibly discharge to the Aberjona River at the Commerce Way/Atlantic Avenue intersection. However, with the recent culvertization of the Aberjona River along Commerce Way, this discharge scenario is not likely to occur.

As seen from analytical data from surface water samples collected in the HBHA (excluding samples collected at the groundwater sediment interface in the HBHA Pond), no significant concentrations of VOCs are present in any of the surface waters sampled. The absence of VOCs in surface water is primarily the result of biological degradation with contributions from other processes such as chemical degradation, dilution/dispersion, and volatilization.

Benzene was also detected in groundwater at elevated concentrations along the east-central portion of the West Hide Pile. However, groundwater data from adjacent and downgradient wells only exhibited benzene at very low concentrations indicating that the benzene plume is likely discharging to the Lower South Pond. Similar to VOC discharges in the HBHA Pond and wetlands as discussed above, impacts would be expected to be localized and minimal due to the effects of biological or chemical degradation, volatilization, and dispersion.

A localized TCE plume has also persisted in deeper groundwater monitoring well locations along Cabot Road since the GSIP investigations conducted in the early 1990s. The recent detected concentrations in groundwater do not exceed MADEP GW-2 or GW-3 standards. The presence of TCE daughter products, DCE, is also noted in these areas indicating that biological degradation is occurring. Based on the observed TCE contamination distribution patterns in groundwater and groundwater flow direction, it appears that TCE may be discharging to the HBHA wetlands and the Aberjona River. These discharges, however, do not appear to be impacting surface water quality indicating that the TCE is being attenuated by similar fate and transport processes as observed for the benzene and toluene.

5.5.1.2 Fate and Transport of SVOCs in Reach 0 (Industri-plex Site and the HBHA)

While SVOCs have been sporadically detected in soils in Reach 0, they do not appear to be mobilizing to groundwater. Although SVOCs were detected in the HBHA and Aberjona River sediments downstream of the Industri-plex Site, they were also detected in reference/background sediment samples. However, the SVOC concentrations detected in the HBHA and other reaches of the Aberjona River were generally above (albeit within same order of magnitude) those observed at background locations.

SVOCs are generally considered to be ubiquitous in the environment, especially in urban areas as a result of anthropogenic activities. Non-volatile organic compounds deposited at the ground

surface will likely adsorb to soil particles. Erosion and runoff can convey these chemicals into the surface water and sediments. Wind erosion may also cause dusts containing SVOCs to be mobilized through the air pathway.

SVOCs adsorbed to sediment or suspended solid particles in surface water would be transported downstream as part of the suspended sediment load and potentially settle in other depositional areas.

5.5.1.3 Fate and Transport of Metals in Reach 0 (Industri-plex Site and the HBHA)

Metals that have been released to Site soils may become mobilized through erosion and runoff, or through fugitive dust emissions as would the non-volatile organic compounds. Although the dominant source of metals contaminants has been capped, thus eliminating erosion as a transport mechanism, a few smaller areas have been identified along the MBTA right-of-way and the small parcel of land between the BECO right-of-way and HBHA Pond, that may be contributing to the lead-contamination in the HBHA Pond and wetlands through erosion.

Based on the evaluation of analytical results, the most significant ongoing transport process for metals underlying the Industri-plex Site is leaching to groundwater. Arsenic appears to be the primary metal that is being mobilized into groundwater at sufficiently high concentrations to exceed the regulatory criteria and drive human health and ecological risks in the HBHA. Other metals of significance detected in groundwater exceeding regulatory criteria include lead and zinc.

Available data indicate that because of biological activity occurring in VOC-contaminated soils (most probably degradation of aromatic hydrocarbons [benzene and toluene] or natural organic carbon from the wetland deposits as well as the degradation of waste animal hides located in the hide piles and BECO right-of-way), a reducing environment has been created at the Industri-plex Site. Capping of the Site with low-permeable soils, bituminous concrete pavement or, in the case of the East Hide Pile, an impermeable cap, may also be contributing to the reducing conditions by decreasing the infiltration of oxygenated water from precipitation. In turn, metals such as arsenic and iron, are being reduced, rendered more soluble, and therefore, much more mobile in groundwater. Metals, such as arsenic, could also be mobilized by the indirect effects of reducing conditions whereby the solid species containing the binding area/site is reduced,

thus releasing the metals bound to the soil grain coating. These actions are evidenced by observed groundwater arsenic levels as well as the presence of arsenic in surface water samples collected in the discharge zones in the HBHA Pond.

Historical and current groundwater data indicate that the primary discharge point for groundwater originating from the Industri-plex Site is the HBHA Pond and downgradient HBHA wetlands to Mishawum Road. Metals contaminated groundwater discharging to the HBHA continues to impact sediments. Long-term surface water monitoring at the HBHA Pond surface water discharge indicates that dissolved arsenic is typically below a concentration of 30 ug/L suggesting that arsenic discharged via Site-derived groundwater is sequestered (albeit not completely) by geochemical and biological processes within the sediments.

The basic chemical reactions controlling arsenic distribution between the sediments and the water column are depicted in Figure 5-3. Generally, arsenic contaminated groundwater is discharged to the HBHA Pond sediments. As the dissolved arsenic passes through the sediment solids rich in iron, sulfur and organic matter, a fraction of the total (dissolved) arsenic is sequestered at the sediment-water interface through reduction processes. Contributing to the dissolved arsenic may also be arsenic that may have bound to ferric oxides, liberated through dissolution. The remaining fraction of dissolved arsenic derived from these two inputs (groundwater and dissolution of ferric oxides) diffuses upward within the water column and is further sequestered from solution during oxidation and precipitation of ferrous iron at the oxic-anoxic interface. The production and dissolution of iron oxides behaves as a steady-state process as long as the chemical stratification is maintained within the water column. Thus, while dissolved arsenic concentrations can become high at depth, shallow water in the oxic zone remains low in dissolved arsenic. Although these reactions are fairly effective in sequestering the arsenic, they are not complete as evidenced by arsenic concentrations in surface water at the outlet of the HBHA Pond relative to concentrations of arsenic typically observed in Halls Brook.

These reactions rely on continuous inputs of oxygen, iron, sulfates, organic carbon, and of course arsenic. Oxygen concentrations at shallow depths in the HBHA Pond are principally derived from Halls Brook discharges and gas exchange at the air-water interface. (The Atlantic Avenue Drainway may also serve as a contributing minor or intermittent source of oxygen.) Electrons involved in iron- and sulfate-reducing processes are derived from microbial

degradation of organic matter within the water column and sediments. Natural and contaminant dissolved organic compounds within the HBHA Pond water column provide a substrate for microbial metabolism, which controls the redox chemistry of the system. Wick et al. (2000) have observed that benzene degradation rates are greatest in the aerobic zone within the HBHA Pond, but degradation of fuel components is still an active process in anaerobic zones (Suarez and Rifai, 1999).

A chemocline at the base of the HBHA Pond remains fairly stable and is somewhat effective in sequestering metals discharging from groundwater during baseflow conditions. However, under storm flow conditions, the mixing and flushing caused by the increased flow rates, specifically from Halls Brook, upset the chemocline balance and more metals, specifically arsenic, are released into the water column. As presented in Section 4, surface water samples at the outlet of the HBHA Pond (i.e. Station 2) show an increase in total arsenic flux, on average, of approximately 20 times greater than observed during baseflow conditions at the same location.

The critical factors maintaining arsenic at depth within the HBHA Pond hypolimnion are the presence of a stable chemocline and the high capacity for arsenic sorption to iron oxides formed at the oxic-anoxic transition zone (Ford, 2004a). The capacity for arsenic sequestration from the HBHA Pond water column is dependent on a continual supply of ferrous iron into the system.

Although the HBHA Pond is the largest open water area within the HBHA system and is the principal discharge point for contaminant plumes originating from the Industri-plex Site, it only represents approximately one-third of the discharge area for groundwater within the HBHA system. Surface water samples collected at Mishawum Road (Station 4) consistently exhibited arsenic concentrations greater than those samples collected at the upstream HBHA Pond outlet (Station 2) during baseflow flow conditions. This suggests several potential fate and transport scenarios including:

- 1) The wetlands and small ponds located south of the HBHA Pond may not have the appropriate geometry (i.e., size, depth, and shape) and subsequent retention time to promote the geochemical reactions necessary to adequately sequester the dissolved and suspended contaminants originating from accumulated metals-contaminated

sediments in those portions of the HBHA wetlands, thus contributing additional arsenic to the water column.

- 2) Similarly, arsenic contaminated sediments in the sediment bed load of the wetland areas may be releasing arsenic through dissolution processes, thus contributing dissolved arsenic to the water column.
- 3) A portion of the arsenic plume originating from the Industri-plex Site is discharging into the HBHA, downstream of the HBHA Pond.
- 4) Metals contaminated groundwater from another source area, such as the buried former Mishawum Lake bed sediments, is discharging into lower portions of the HBHA beyond the HBHA Pond (as evidenced by elevated concentrations of dissolved arsenic in surface water samples collected at Station 3). The presence of the TCE plume may also be contributing to the mobilization of metals in this area by serving as a carbon source for microbial metabolic processes, thus aiding in the creation of a reducing environment.
- 5) A combination of all of the above is the most probable scenario occurring within the MSGRP RI Study Area.

Suspended sediments were found to generally correlate with total metals concentrations, in particular during baseflow conditions. The overall trend observed for suspended sediments is that when there is a rise in TSS concentrations, there is often a rise in metals concentrations. This trend is apparent for both baseflow and storm flow conditions.

Once in the water column, metals bound to soil particles can be transported downstream as part of the suspended sediment load or become re-dissolved within the water column and be transported downstream where they can be re-adsorbed onto other soil particles and possibly precipitate out to once again become part of the sediment base load. This cycle of adsorption, dissolution, re-suspension, and precipitation can repeat itself indefinitely depending upon the geochemical and hydrodynamic conditions that exist within the environment.

5.5.1.4 Summary of Conceptual Fate and Transport at the Industri-plex Site and the HBHA (Reach 0)

The principal source areas of contamination within Reach 0 include:

- large portions of the Site dominated by ubiquitous metals contamination (i.e. arsenic, lead, and zinc) in soils below the Soil Remedy cap are impacting Site groundwater and downgradient discharge areas;
- surface soils in Area 6, between the BECO right-of way and the HBHA Pond are contaminated with arsenic, chromium , and lead and may be impacting HBHA sediments and surface water;
- HBHA Pond sediments contaminated with arsenic as a result of groundwater discharges are impacting surface water and downgradient depositional areas;
- groundwater contaminated with benzene in the vicinity of the western portion of Atlantic Avenue;
- subsurface soil and groundwater contaminated with benzene along the eastern edge of the West Hide Pile;
- groundwater contaminated with toluene in the vicinity of the intersection of Atlantic Avenue and Commerce Way; and
- buried waste deposits along the eastern portion of the BECO right-of-way wetland and buried sediments from the former Mishawum Lake are also impacting groundwater with arsenic.

Contaminant patterns at surface water Station 1 indicate that during storm events, slightly elevated concentrations of chromium and lead are also being discharged into the HBHA Pond from Halls Brook. The source for this contamination is likely the New Boston Street Drainway and the East Drainage Ditch based on surface water quality samples collected during construction of the remedy and sediment data collected during this investigation. Historically,

Olin Chemical Corporation has been identified as a source of chromium in sediments along the East Drainage Ditch.

Generally, groundwater from the Industri-plex Site is flowing in a southerly direction and is discharging to the HBHA Pond and HBHA wetlands. Groundwater water flow at greater depths may be in part, flowing upward to the shallow groundwater and subsequently discharging to the HBHA Pond and downgradient wetlands, but generally continues to flow parallel to the main buried valley. As evidenced by downgradient groundwater sample data, the deeper portion of the aquifer does not appear to be a significant pathway for contaminant migration as contaminant concentrations are not being sustained. These contaminants are likely being attenuated by biological and chemical degradation and dispersion processes that are significantly influenced by geochemical conditions.

Due to its proximity to the Lower South Pond and wetlands, groundwater along the eastern edge of the West Hide Pile, where the benzene was detected, is likely discharging to the surface water of the adjacent pond and wetland areas as evidenced by groundwater samples downgradient of the West Hide Pile. Once discharged to the sediments and surface water, the benzene is likely being attenuated by biodegradation, chemical degradation, volatilization, and dispersion.

The overall conceptual fate and transport of contaminants at the Site and the HBHA Pond is illustrated in Figure 5-3. In general, Site contaminants in soils are migrating to groundwater. Significant contaminants found in groundwater include arsenic, benzene, toluene, and to a lesser degree lead and zinc. Contaminants are then transported through groundwater flow paths and are predominantly discharged in the northern portions of the HBHA Pond, impacting sediments and surface water. Fate and transport mechanisms affecting sediments and surface water are complex and dependent upon the localized geochemistry. Once discharged into the sediment and deeper portions of the HBHA Pond, organic compounds are generally attenuating to very low concentrations or are not detected. A fraction of the dissolved arsenic becomes bound to ferric oxides and effectively removed from the water column and become part of the sediment load. However, a portion of the dissolved arsenic continues to migrate through the sediments, diffusing further into the water column whereby the arsenic can either be further sequestered from solution during oxidation and precipitation of ferrous iron at the oxic-anoxic interface or be transported downstream. These reactions are dependent upon a fairly stable

chemocline induced by the difference in specific conductance between oxic surface water and anoxic contaminated groundwater, and steady inputs of oxygen, iron, sulfate, and organic carbon. Sudden increases in flows, as seen during storm conditions, mix the water column and break down the chemocline thus allowing more arsenic to be “flushed” downstream. However, the chemocline has been shown to be re-established within a period of less than a month due to the continuous flux of high specific conductance groundwater (Ford, 2004b).

Once in the surface water column, as either dissolved or associated with the suspended solid load, arsenic will continue to migrate downstream with the flow of water. Depending on the geochemical and flow conditions, dissolved metals in the water column may absorb to suspended solids, such as fine grained soil particles or other metal complexes and either precipitate and become part of the sediment bed load or be transported further downstream as part of the suspended solid load within the water column and be deposited at locations downstream.

As part of the sediment bed load and depending on the geochemical conditions, metals may dissolve from the sediment particle back into the surface water, whereby the cycle of dissolution and precipitation would continue. This cycling was mostly observed within portions of the HBHA that exhibited significant anoxic/reduced conditions, specifically, within the HBHA Pond. Therefore, even if the groundwater source of arsenic is eliminated, the arsenic existing in the sediment bed load could continue to impact surface water (EPA, 2005). Whereas wetlands in general typically exhibit reduced conditions or present a significant source of sulfides under oxic conditions, this cycling may also be occurring at other portions of the HBHA, but probably not as significant as observed in the HBHA Pond.

As previously stated, suspended sediments were found to generally correlate with total metals concentrations, specifically iron, and in particular, during baseflow conditions. The overall trend observed for suspended sediments is that when there is a rise in TSS concentrations, there is often a rise in metals concentrations.

The outlet structure of the HBHA wetland area, located at Mishawum Road, serves as a flow restriction during storm events, causing water to be retained in the HBHA wetlands. During storm flow conditions, the water floods the HBHA, decreasing flow and allowing suspended solids to precipitate and/or be filtered by over 15 acres of dense vegetation. Based on the

surface water data, the concentration of arsenic decrease between Stations 2 and 4, however, they still remain elevated as the water column continues downstream to Reach 1 (Wells G&H wetlands).

5.5.2 Conceptual Fate and Transport Model for Reach 1 (Wells G&H Wetland)

As previously stated, organic compounds originating from the Industri-plex Site have been shown to attenuate within Reach 0. Only metals contaminants have been shown to have migrated from Reach 0 into Reach 1 through dissolved and sediment transport mechanisms in surface water during both baseflow and storm flow conditions. Therefore, the following discussions for Reach 1 are limited to the conceptual fate and transport of metal contaminants and impacts to surface water and sediments. In addition, groundwater collected for the MSGRP RI investigation have also shown that groundwater contamination by organic compounds at the Wells G&H Site did not originate from the Industri-plex Site and is due to more localized sources. It is noted that groundwater at the Wells G&H Site is currently being investigated, and in some areas remediated as part of the Wells G&H Superfund Site cleanup program being conducted under the auspices of the EPA and MADEP. Therefore, with the exception of the groundwater/sediment interaction, discussions relative to the fate and transport of contaminants in groundwater at the Wells G&H Site are not presented in this document.

Flows from Station 3 (Aberjona River) and Station 4 (HBHA) combine at Mishawum Road and then continue toward the Wells G&H wetland. As evidenced by surface water and sediment data, source areas within the Wells G&H wetlands are dominated by wetland sediments contaminated with metals deposited by surface water from upstream sources during baseflow and storm flow conditions. An additional potential source area for chromium contamination is the former JJ Riley property adjacent to the southwestern portions of the Wells G&H wetland, specifically, southwest of the Wildwood property. Twenty samples collected by EPA in 2004 from wetlands and a drainage channel on the former JJ Riley property that discharge to the Wells G&H wetlands exhibited chromium concentrations ranging from 386 mg/kg to 47,100 mg/kg, with an average concentration of 7,861 mg/kg (Weston, 2004). As noted in Section 4, wetland sediment samples collected from the Wildwood property at 12 locations under the MSGRP RI investigation exhibited elevated chromium concentrations ranging from 3,670 mg/kg to 24,600 mg/kg with an average concentration of 12,012 mg/kg. It is not clear at this time whether or not groundwater at the former JJ Riley property has been impacted by these

chromium deposits or that groundwater is discharging to the Wells G&H wetland. Also, depending on the extent of operations at the former JJ Riley property, documented past disposal practices where settling lagoons were used may have contributed to historical chromium contamination in the Wells G&H, as well as currently contributing to sediment and surface water contamination within the lower portions of the Wells G&H wetland and depositional areas further downstream. Based on this limited information, it is likely that the former JJ Riley property, in part, contributes chromium to the Wells G&H wetland sediments and surface water.

Lead was detected at elevated concentrations in sediment samples collected along the eastern edge of the Wells G&H wetland and sporadically throughout the wetland (refer to Section 4). A potential source of the lead may be from a local rifle range that abuts the wetland to the east. During the MSGRP RI sampling activities, lead shot was observed in several sediment samples collected several hundred yards downrange of the shotgun range at concentrations ranging from 383 mg/kg to 41,000 mg/kg.

5.5.2.1 Fate and Transport of Metals in Reach 1 (Wells G&H Wetland)

As discussed for Reach 0, dissolved metals or metals bound to suspended particles can either remain in the water column and continue their transport further downstream or bind to other particles and precipitate out, becoming part of the sediment bed load. As part of the bed load and depending on the geochemical conditions, metals can dissolve to the water column in a dissolved state or be liberated into the water column as part of the suspended solids load due to scouring during storm events and then be transported further downstream.

Based on the surface water investigation data (see Appendix 2C), the average concentration of total arsenic entering the Wells G&H wetlands from Stations 3 and 4 (combined) during baseflow conditions observed during the 18-month study period, was approximately equal to 56.3 ug/L and the average total arsenic flux was 9.4 g/hr. However, the average concentration of total arsenic at the Wells G&H wetlands outlet, as measured at Station 5, was 20.1 ug/L and the average total arsenic flux was 5.3 g/hr indicating that some deposition was occurring between Stations 3/4 and Station 5. This pattern was also more dramatically observed with iron, where the average concentration of total iron entering the Wells G&H wetlands from Stations 3 and 4 (combined) during baseflow conditions was approximately equal to 7,660 ug/L

and the average total iron flux was 1,280 g/hr compared to Station 5, where the average total iron concentration was 2,448 ug/L and the average total iron flux as 660 g/hr. These values are summarized below.

Station	Arsenic Conc. (ug/L)	Arsenic Flux (g/hr)	Iron Conc. ug/L	Iron Flux (g/hr)
Station 3&4 (combined)	56.3	9.4	7,660	1,280
Station 5	20.1	5.3	2,448	660

Similar patterns of decreasing metal concentration were also observed with other metals such as chromium, copper, and lead. The data suggest that deposition of some metals is occurring in the Wells G&H wetland during baseflow conditions.

Concentrations of arsenic during storm conditions follow a similar trend. However, the arsenic flux at Station 5 is greater than the flux at Station 3/4. This trend deviation would be due to the increase in the volume of water and flow between Stations 3/4 and Station 5 during storm events that would cause dilution but increase flux.

Lead was detected in sediments at numerous locations throughout the Well G&H wetland. Similar patterns of concentrations and flux for lead, as discussed above for arsenic and iron, were observed, indicating that deposition of lead is occurring in the Wells G&H wetland. Another potential contributor to lead in the wetlands is lead shot originating from the Massachusetts Rifle Association shotgun range. Lead shot exposed to acidic water or soil, could break down to soluble compounds such as lead salts, oxides and carbonates. Once in the soluble form, lead can migrate with storm runoff to other areas downstream. However, in soils and sediments, the lead forms salts in the presence of humic acids and will tend to bind to humic materials and to clayey soils because of ionic attraction, thus retarding its mobility in groundwater. This is evidenced by groundwater data collected within the Central Area aquifer of the Well G&H Superfund Site in 2002 where lead was generally detected at an order of magnitude less than the EPA drinking water action levels for lead (15 ug/L) (TRC, 2005).

Sediment Impacts to Groundwater

Similar to the transport processes that cause contaminated groundwater to contaminate sediments, and contaminated sediments to dissolve to surface water, once deposited as part of the sediment load, metals-contaminated sediments could potentially impact underlying groundwater. This reaction would be predicated on geochemical conditions that cause the dissolution of metals from the sediment particles and the existence of a hydraulic gradient such that the stream would discharge to groundwater, as in the case of elevated stage level during storm conditions.

In most cases the observed impacts to groundwater within the Wells G&H wetland are localized, within the shallow aquifer, as a result of temporary fluctuations in the stream stage due to storm flows and diffusion processes. Several wells within the Wells G&H wetland that exhibit arsenic concentrations exceeding regulatory criteria exist within the shallow aquifer. However, concentrations of arsenic diminish with depth (TRC, 2005).

The Well G&H wetlands lie within the boundaries of an Interim Wellhead Protection Area for a medium to high yield drinking water aquifer (i.e. GW-1). Although the use of the municipal drinking water production wells, Well G and Well H, have been suspended indefinitely, a hydraulic gradient could be dramatically influenced both vertically and horizontally if the wells were returned to service or if other production wells, either for commercial or municipal uses, were installed. However, as discussed previously, the Site conditions (subsurface geology), actual pumping conditions, and geochemical reactions that govern mobilization are complex and will likely limit migration patterns.

In 2004 to 2005, TRC Environmental Corporation (TRC) conducted a study to evaluate the possible effects of arsenic and heavy metal contaminated sediments in the Aberjona River and Wells G&H wetlands on future drinking water withdrawal scenarios (see Appendix 5A). TRC concluded that the preponderance of evidence from this evaluation suggests that the arsenic and other metals in the sediments would not adversely affect the development of large-capacity potable water supply wells in the aquifer. The evidence that led to this conclusion includes historical water quality data from municipal Wells G and H; information regarding the hydrologic relationship between the aquifer, the river and the wetlands; geochemical conditions existing in the aquifer; recent water quality data from the sampling of various monitoring wells and surface

water stations during site investigations; and known and postulated geochemical behavior of the contaminants and associated metals, notably iron and manganese. Subsequent samples taken from Wells G&H, including one set taken during a 30-day pumping test in 1985/1986, showed arsenic concentrations to be less than the EPA 2006 Maximum Contaminant Limit (MCL) of 10 ug/L. In addition, concentrations in other pumping wells nearby (the former J.J. Riley production wells) have not been shown to contain arsenic above the current EPA MCL of 10 ug/L.. These results suggest that arsenic in the river and sediments does not reach the deep part of the aquifer at concentrations high enough to result in levels above 10 ug/L in the former supply wells (TRC, 2005).

5.5.3 Conceptual Fate and Transport Model for Reaches 2 through 6

As previously stated, organic compounds originating from the Industri-plex Site have been shown to attenuate within Reach 0. Only metals contaminants have been shown to migrate from Reach 0, to Reach 1, and into Reaches 2 through 6 through dissolved phases and sediment transport mechanisms during both baseflow and storm flow conditions. Therefore, the following discussions will be limited to the conceptual fate and transport of metal contaminants and impacts to surface water and sediments.

As with Reach 1, contaminated areas within Reaches 2 to 6 are dominated by sediments contaminated with metals deposited by surface water from upstream sources during baseflow and storm flow conditions. As discussed in Section 4, another potential minor arsenic source area may be present at the JO Whitten property in Winchester, MA, a former tannery and rendering facility. Arsenic concentrations in 26 site and flood plain soil samples collected in 2000 ranged from 4.6 mg/kg to 103 mg/kg. These data would indicate that there is not a significant source of arsenic onsite. However, four sediment samples collected adjacent to the JO Whitten site in the Aberjona River exhibited arsenic concentrations ranging from 34.3 mg/kg to 143 mg/kg at locations upstream of the site to 490 mg/kg at a location downstream of the site (Weston, 2001). Although, the depositional nature of the sample locations where the samples were collected is unclear, it would appear that the floodplain soils on the site may be providing some minor contribution of arsenic to the river.

Deposition from other historical sources may have occurred, but direct impacts have not been documented. No other current sources, other than the existing sediments are known to exist.

5.5.3.1 Fate and Transport of Metals in Reaches 2 through 6

As discussed for Reach 0 and Reach 1, dissolved metals or metals bound to suspended particles can either remain in the water column and continue their transport further downstream or bind to other particles and precipitate out, becoming part of the sediment bed load. As part of the bed load and depending on the geochemical conditions, metals can dissolve into the water column or be liberated into the water column due to scouring effects caused by increased flows during storm events to again be transported further downstream as part of the suspended solid load.

Several areas of deposition have been identified within the Aberjona River in Reaches 2 to 6. These areas were targeted for sediment sampling as part of the MSGRP RI investigation to evaluate potential impacts of metals contamination. These areas included: the Cranberry Bog Conservation Area (Reach 2-North), the wetland areas adjacent to Kraft Foods (Reach 2-South), Davidson Park (Reach 3), wetlands adjacent to Swanton Street Condominium complex (Reach 3), Judkins Pond (Reach 4), Mill Pond (Reach 5), wetland area adjacent to the Wedgemere train station (Reach 5), and the Upper and Lower Mystic Lakes.

Although elevated metals concentrations, in particular arsenic, were observed in sediments in all of the above mentioned depositional areas, the northern part of the MSGRP RI Study Area generally exhibited higher concentrations than those areas in the south.

Based on the surface water data, surface water clearly is the transport mechanism that is facilitating arsenic (and other metals) transport through the river system. This fate and transport mechanism is clearly demonstrated by the baseflow and storm flow surface water sample data collected during the 18-month investigation. Based on these data, the highest concentrations of arsenic are in the northern part of the MSGRP RI Study Area and steadily decrease south. Concentrations of arsenic and other metals and TSS in surface water at the furthest downstream monitoring stations (Stations 9 and 10) decrease during both baseflow and storm flow conditions indicating further deposition, dilution, or a combination of both (also refer to Section 4.5 and Appendix 2C).

This finding is consistent with previous work conducted by MIT. Historically, the Mystic Lakes have served as a deposition area for the Aberjona River. In 1995, MIT collected and dated

freeze-core sediment samples from the bottom of the Mystic Lakes. This study concluded that the greatest amount of deposition of arsenic from the Aberjona River into the lakes occurred during the height of industrial activity along the river during the late 1800s to early 1900s. Although the amount of contaminant deposition has dropped off considerably since that time, the metals in sediments continue to be deposited at levels above natural background concentrations, especially for arsenic (Spliethoff and Hemond, 1996).

Sediment Impacts to Groundwater

As discussed for Reach 1, metals in contaminated sediments, once deposited as part of the sediment load, could potentially impact underlying groundwater. This reaction would be predicated on geochemical conditions that cause the release of the metals from the sediment particles into a dissolved state and the existence of a hydraulic gradient such that the stream would discharge to groundwater, as in the case of elevated stage level during storm conditions. No groundwater investigations have been conducted in Reaches 2 through 6 as part of the MSGRP RI. However, as shown in Reach 1, if the geochemical conditions were present to initiate this fate and transport mechanism, the reactions would not be expected to be sustained and the impacts to groundwater would be minimal and localized.

6.0 BASELINE HUMAN HEALTH RISK ASSESSMENT SUMMARY

Baseline Human Health Risk Assessments have been prepared for the Northern and Southern Study Areas of the MSGRP RI by Metcalf & Eddy, Inc. for USEPA Region I. The Southern Study Area Risk Assessment, entitled *“Baseline Human Health and Ecological Risk Assessment Report, Wells G&H Superfund Site, Aberjona River Study, Operable Unit 3,”* was released by USEPA in September 2004 (M&E, 2004). The Northern Study Area Baseline Human Health Risk Assessment is contained within Appendix 6 of this report. This section of the MSGRP RI provides a comprehensive summary of the Northern and Southern Study Area Baseline Human Health Risk Assessments.

The two risk assessments comprehensively evaluate the area from the Industri-plex Superfund Site south to Interstate 95/Route 128 in Woburn (Northern Study Area; Reach 0) and from Interstate 95/Route 128 south to, and including, the Mystic Lakes in Winchester and Medford (Southern Study Area; Reaches 1 through 6). Significant features of the Northern and Southern Study Areas include the Industri-plex and Wells G&H Superfund Sites, Halls Brook Holding Area (HBHA), Aberjona River, Mystic Lakes, and associated wetland areas. The Wells G&H Interim Wellhead Protection Area (IWPA) is part of the Southern Study Area. The northern edge of the IWPA abuts the Northern Study Area. Municipal wells G and H are inactive, but are still considered a potential source of public drinking water in the future.

6.1 Purpose and Approach

The objective of the Northern Study Area and Southern Study Area Baseline Human Health Risk Assessments is to determine whether contaminated media (surface water, sediment, sediment cores, fish, soil, groundwater, and soil gas) pose risks to human health. The two risk assessments were prepared using current USEPA risk assessment guidance documents and protocols, along with site-specific assumptions applied consistently across the two study areas. The consistent application of methodology across both study areas allows for the formulation and discussion of comprehensive risk results and conclusions applicable to the river as a whole. The comprehensive risk assessment results will be used to identify media, exposure pathways, and chemicals of greatest potential concern, and will provide the basis for decisions as to whether remedial actions are necessary.

For the purposes of the risk assessments, the two study areas were divided into stations. Stations are defined as areas of recreational use (e.g., wading or swimming) along the Aberjona River, Mystic

Lakes, HBHA, and associated wetland/floodplain areas at which human exposures to multiple environmental media (i.e., soil, sediment, and surface water) may occur. Additional areas containing residual soil contaminants (e.g., the former Mishawum Lake bed) were also evaluated. Groundwater collected from the two study areas was also of interest to determine potential contaminant impacts to the Wells G&H IWPA from the river and the upgradient Northern Study Area. In addition, Northern Study Area groundwater was comprehensively evaluated for potential direct (e.g., industrial use) and indirect (e.g., subsurface migration to indoor air) contaminant exposures. Groundwater within the Central Area of the Wells G&H Superfund Site is scheduled for comprehensive evaluation by USEPA.

Prior to completion of the two risk assessments, an arsenic bioavailability study was performed to assist in the quantification of sediment risks (see Appendix 6K). This site-specific study, applicable to both study areas, determined that arsenic is absorbed less efficiently from sediment than from a water medium. The relative bioavailability estimate determined in this recent study was used to quantify sediment ingestion risks at the study areas. In addition, site-specific chromium VI (hexavalent chromium) data for sediments (for the Northern and Southern Study Areas) and soils (for the Northern Study Area) were collected and used in the risk assessments to more accurately characterize sediment and soil risks at the study area (see Appendix 6F).

For both assessments, 95% Upper Confidence Limits (UCLs) were calculated using USEPA=s software program ProUCL version 3.0, and used as exposure point concentrations (EPCs) whenever possible.

6.2 Medium-Specific Risk Summary

The following presents a discussion of the results of the risk assessments, organized by medium. For both study areas, potential noncarcinogenic and carcinogenic human health hazards and risks for the central tendency (CT) and reasonable maximum exposure (RME) cases were estimated. CT estimates are indicative of average risks and hazards, while RME estimates are used to represent upper-bound risks and hazards that are reasonably expected to occur. RME estimates are primarily used as the basis for remedial decisions.

Overall summaries of estimated carcinogenic risks and noncarcinogenic hazards are presented in Tables 6-1 through 6-6, by media. Cumulative receptor risks and hazards, summed across all applicable media, are provided in the Northern and Southern Study Areas Baseline Human Health

Risk Assessments. When risks and hazards were estimated for both the young child and adult receptors (e.g., fish consumers), the young child noncarcinogenic hazard is presented as the most conservative, while the cancer risk presented is the sum of the young child and adult risks (i.e., a total receptor risk).

Figures 6-1 through 6-3 depict locations where estimated risks and hazards exceed the USEPA target cancer risk range of 10^{-6} to 10^{-4} and/or a target hazard index of 1 for noncarcinogenic effects. Note that some stations have not been quantitatively evaluated in the human health risk assessments because they were judged to be difficult for humans to access due to the presence of dense vegetation, deep surface water, and/or their distance from the shoreline.

6.2.1 Sediment

Recreational exposures evaluated included incidental ingestion of and direct dermal contact with sediments. Recreational receptors (young children, teenagers, and/or adults) were selected for evaluation at individual stations after consideration of current and reasonable potential future land use (e.g., residential, park land, or commercial). Table 6-1 summarizes the recreational risks and hazards at each station.

Current risks associated with sediment exposure exceeded USEPA risk management criteria at Station WH, located near well H in the Wells G&H 38-acre wetland north of Salem Street in Woburn, and Station CB-03, located on the western side of the former cranberry bog immediately south of Salem Street. Figure 6-1 shows the locations of the sediment stations associated with current risk in excess of regulatory guidelines.

For the future scenario, risks above risk management criteria were estimated at Stations 13/TT-27, WH, NT-1, NT-2, NT-3, and CB-03. All stations noted are located within the Wells G&H 38-acre wetland except for Station CB-03, the sample in the former cranberry bog. Stations NT-1, NT-2, and NT-3 are areas within potential future land use scenarios developed by the City of Woburn within the Wells G&H wetland that may include the construction of a nature trail (Station NT-3) with a possible boardwalk (Station NT-1) or pier (Station NT-2) extending out into the wetland. Station 13/TT-27 is located on the western side of the Wells G&H 38-acre wetland.

The risk exceedances were due primarily to the presence of arsenic in sediment. For Stations 13/TT-27, WH, and CB-03, areas of significantly elevated arsenic concentrations were localized in

nature. Benzo(a)pyrene was also a minor risk contributor at Stations 13/TT-27, WH, NT-1, and NT-2. The risk associated with benzo(a)pyrene and the concentrations of benzo(a)pyrene present at these stations fall within the range of estimated risks and detected concentrations at the reference stations.

The City of Woburn's most recent redevelopment plan (February 2005; see Appendix 6N) no longer includes the construction of a boardwalk (Station NT-1) or pier (Station NT-2) into the wetland. Should the redevelopment plan remain unchanged, the sediment exposure pathways associated with Stations NT-1 and NT-2 would be considered incomplete. Therefore, based on the draft redevelopment plan, sediment exposures at these two stations are not expected to occur in the future and the risk and hazards previously identified for Stations NT-1 and NT-2 may not require further consideration. The City's redevelopment plan continues to identify the construction of a nature trail (Station NT-3) in the Wells G&H 38-acre wetland as a possible land use option. Therefore, the risks and hazards identified for Station NT-3 are anticipated as requiring further consideration. These decisions will be reviewed upon finalization of the City's redevelopment plan. Hence, Figure 6-1 shows the future sediment stations associated with risk in excess of regulatory guidelines, excluding Stations NT-1 and NT-2 which are not discussed in Section 6.4, Human Health Risk Conclusions. Decisions concerning these stations will be reviewed further when the redevelopment plan is finalized, if necessary.

6.2.2 Sediment Cores

Sediment cores were evaluated for a potential future dredging scenario which assumed that workers would contact contaminated sediments up to four feet in depth during excavation for flood mitigation and control. Worker exposures evaluated included incidental ingestion of and direct dermal contact with sediments. Table 6-2 summarizes the potential dredging worker risks and hazards at each sediment core location.

For the future scenario, risks above risk management criteria were estimated at sediment core locations SC02, located in the HBHA wetland, and SC05, SC06, and SC08, located within the Wells G&H 38-acre wetland. Figure 6-1 also shows the sediment core locations associated with future risk in excess of regulatory guidelines. The risk exceedances were due primarily to the presence of arsenic in sediment.

6.2.3 Surface Water

Recreational exposures evaluated included incidental ingestion of and direct dermal contact with surface water while swimming at the Sandy Beach, the public beach located in Winchester (Station 01). Dermal contact with surface water while wading was evaluated at all other stations. Recreational receptors (young children, teenagers, and/or adults) were selected for evaluation at individual stations after consideration of current and potential future land use (e.g., residential, park land, or commercial). Exposure to surface water contaminants under baseflow as well as during storm events was considered. The surface water evaluation also considered the potential migration of contaminants to nearby residences during flooding events and subsequent residential exposures. Table 6-3 summarizes the baseflow surface water risks and hazards at each station. Risks and hazards associated with exposure to contaminants present in surface water during storm events are comparable to those presented for the baseflow exposures. Surface water risks and hazards do not exceed USEPA risk management criteria at any station.

6.2.4 Fish Fillet Tissue

The families of recreational fishermen may consume fish caught from the two study areas (Reaches 0 to 6). Therefore, fish fillet ingestion risks and hazards were estimated for both young children and adults exposures. Because fish of edible size were not captured from Reaches 1 and 2 where surface water is shallow, fish ingestion risks were not estimated for these reaches. Table 6-4 summarizes the recreational fish ingestion risks and hazards, by reach. Fish ingestion risks and hazards for an adult and young child do not exceed USEPA risk management criteria within any river reach.

6.2.5 Soil

Recreational exposures evaluated included incidental ingestion of and direct dermal contact with floodplain soils. Recreational receptors (young children, teenagers, and/or adults) were selected for evaluation at individual stations after consideration of current and potential future land use (e.g., residential, park land, or commercial). The soil evaluation also considered the potential migration of floodplain contaminants to nearby residences and subsequent residential exposures. In addition, residual soil contaminants within the former Mishawum Lake bed were evaluated for potential exposures to current and/or future day care children, groundskeepers, and construction workers.

Table 6-5 summarizes the current and future soil risks and hazards for each receptor and station/area.

For the future scenario, risks and hazards in excess of risk management criteria were estimated for future day care children exposed to surface and subsurface soils within the former Mishawum Lake bed area. Noncarcinogenic hazards also exceeded USEPA risk management guidelines for future construction workers exposed to subsurface soils within the former Mishawum Lake bed area. The exceedances were due primarily to the presence of arsenic in surface soil at locations SO-13, SO-14, and SO-16, and arsenic in subsurface soil at locations SO-13, SO-11, SO-3, and SO-14. Figure 6-2 shows the soil locations associated with future risk in excess of regulatory guidelines.

6.2.6 Groundwater

MADEP has evaluated the use and value of the groundwater aquifers within and in the vicinity of the Industri-plex and Wells G&H Superfund Sites. MADEP's groundwater use and value determinations support a low use and value for groundwater at the Industri-plex Superfund Site (MADEP, 1997) and a medium use and value for groundwater at the Wells G&H Superfund Site (MADEP, 2004). Therefore, Northern Study Area groundwater exposures evaluated included: (1) vapor seepage into buildings; (2) use of groundwater in industrial processes; and (3) worker exposures associated with excavations into groundwater. As part of a risk assessment planned for Operable Unit 2 of the Wells G&H Superfund Site, the evaluation of the Central Area groundwater within the Southern Study Area will include the above-listed exposures. In addition, because of the MADEP groundwater determination, Central Area groundwater will be evaluated for future potable and other household uses.

Because of the potential for future potable use of groundwater from the Central Area, groundwater contaminant levels within the wetland portion of the Central Area were compared to Federal Maximum Contaminant Levels (MCLs) as a preliminary indication of groundwater impacts associated with the sediments and surface water of the river and wetland. Groundwater concentrations at the southern edge of the Northern Study Area (i.e., the AF-series and P-1 transect wells between Mishawum Road and Interstate 95/Route 128) were also compared to MCLs to determine potential impacts to the downgradient IWPA.

6.2.6.1 Northern Study Area Groundwater Evaluation

Specific industrial groundwater use evaluated in the Northern Study Area Human Health Risk Assessment included process water use (ingestion, dermal contact, and inhalation exposures) and the use of groundwater in a warm water car wash (inhalation exposures). Because groundwater throughout the study area is shallow, future construction workers may also be exposed to groundwater contaminants during excavations down to the water table. Table 6-6 summarizes the future groundwater risks and hazards for each receptor.

Soil gas sampling data were collected to more accurately characterize potential groundwater volatile impacts to indoor and outdoor air quality within the study area. However, no contaminants detected in soil gas were found to exceed conservative screening values. Therefore, this pathway was not quantitatively evaluated in the Northern Study Area Baseline Human Health Risk Assessment.

Risks and hazards in excess of USEPA risk management criteria were estimated for Northern Study Area groundwater used as process water, used in a warm water car wash, and for worker-related exposures to shallow groundwater. Primary risk contributors for process water use and the use of groundwater in a warm water car wash include benzene, trichloroethene, and naphthalene. Arsenic was also identified as a primary risk contributor for the process water exposure scenario and for worker-related exposures to shallow groundwater. For these primary risk contributors, the highest concentrations were seen in monitoring wells: B7-01, B4-04, B7-02, B6-03, B5-02, and B8-04 for arsenic; B5-01, W5-06, W5-05, B7-03, B9-02, B9-01, and W5-03 for benzene; AE-03, W5-03, AE-02, AE-04, and AE-06 for trichloroethene; and W5-05 for naphthalene. Figure 6-3 shows the monitoring well locations associated with future risk in excess of regulatory guidelines.

Additional minor risk contributors for process water and warm water car wash use include: 1,2-dichloroethane, chloroform, and methyl tert-butyl ether. Pentachlorophenol was also identified as a minor risk contributor for the process water exposure scenario.

6.2.6.2 Comparison to MCLs

Contaminant concentrations in the P-1 transect and the AF-series monitoring wells, immediately upgradient of the Wells G&H IWPA, and in monitoring wells within the Wells G&H 38-acre wetland, within the Wells G&H IWPA, were compared to primary and secondary MCLs. MCLs, as standards protective of domestic water use, were selected for the comparison because groundwater may be

used as a source of potable water in the future. Groundwater data collected from within the Wells G&H 38-acre wetland provide preliminary information on the potential impact of sediments and surface water contamination on groundwater quality within the Wells G&H IWPA. Groundwater data from the P-1 transect and AF-series wells provide information on the potential for upgradient impacts to the Wells G&H IWPA.

Total metals groundwater data collected from within the Wells G&H 38-acre wetland and from the AF-series wells in 2002 were not reported as containing elevated levels of total suspended solids and are considered representative of groundwater quality within the Wells G&H IWPA and as it leaves the Northern Study Area and enters the Wells G&H IWPA. Because a number of the P-1 transect wells could not be stabilized prior to sampling and may have contained elevated levels of total suspended solids, filtered metals results were used for comparison to MCLs for the P-1 transect wells.

Figure 6-4 depicts the monitoring wells in which exceedances of primary MCLs were noted. Only arsenic exceeded its primary MCL. Shallow overburden arsenic concentrations in eleven of the twenty-three monitoring wells exceeded the arsenic MCL (10 µg/L). The arsenic primary MCL was also exceeded in one medium overburden well (P1-02) and two deep overburden wells (P1-02 and P1-03). Secondary MCLs for aluminum, iron, and manganese were exceeded in shallow, medium, and deep overburden groundwater.

Arsenic MCL exceedances at the northern boundary of the Wells G&H IWPA appear to be sporadic and spatially limited. A Technical Memorandum entitled *“Possible Effects of Arsenic and Heavy Metal in Sediment and Surface Water on Future Potable Water Supply Development in the Central Area Aquifer at the Wells G&H Superfund Site”* was prepared to evaluate the likelihood that arsenic and other heavy metals in sediments and surface water within the 38-acre wetland could migrate to the municipal wells under future pumping conditions. The evidence evaluated in the Technical Memorandum suggests a limited potential for the migration of arsenic from surface water and sediments to a future supply well within the Wells G&H IWPA at a concentration above the MCL. Therefore, the sporadic presence of arsenic in groundwater at the southern boundary of the Northern Study Area and in shallow groundwater within the Wells G&H IWPA, which may be associated with arsenic contamination in sediments and surface water, is unlikely to be a potential risk to future supply wells within the IWPA, and will not be presented in Section 6.4, Human Health Risk Conclusions.

6.3 Uncertainty Summary

The non-carcinogenic hazards and carcinogenic risks estimated in this assessment are subject to numerous uncertainties. In each step of the assessment, assumptions were adopted that would be reasonably anticipated to result in a health-protective evaluation. A complete discussion of the sources of uncertainty can be found in the Northern and Southern Study Area Baseline Human Health Risk Assessments (Appendix 6; M&E, 2004). The following summarizes the major sources of uncertainty in the risk assessments:

- A site-specific relative bioavailability study was performed to decrease the uncertainty associated with the degree of absorption following incidental ingestion of arsenic-containing sediment (Appendix 6K). The most conservative Abest estimate@ (i.e., the midpoint of the 90% confidence interval) relative bioavailability value was used in the human health risk assessment to characterize the risk associated with sediment ingestion. Use of the most conservative Abest estimate@ of oral bioavailability may have resulted in an overestimate of risk. However, risk estimates may also have been underestimated should oral absorption be greater than predicted in the study for sediments containing arsenic outside the concentration range used in the study.
- A chromium speciation study was performed for sediments within the Northern and Southern Study Areas, and for soils within the Northern Study Area (Appendix 6F). This study resulted in site-specific chromium speciation data that were used to more accurately characterize risk associated with chromium exposures. The chromium speciation study indicated that approximately 0.13% of total chromium in Southern Study Area sediments, 1% of total chromium in Northern Study Area sediments, and 2% of total chromium present in Northern Study Area soils existed in the hexavalent state, the more toxic form. Use of these percent hexavalent chromium assumptions, when applied to sample results for which only total chromium was reported by the laboratory, may result in either an underestimate or overestimate of risk depending on the representativeness of the percent values to the entire data set.
- To better quantify exposure point concentrations, USEPA's software program, Pro UCL version 3.0, was used to determine Upper Concentration Limits (UCLs). This software has been extensively reviewed and provides the best available science for the statistical determination of EPCs. The use of this program is believed to result in the more accurate

estimation of EPCs than previously used methods. However, in cases where there is high degree of variability between the data points for a contaminant, a UCL may be uncertain. For example, the sediment EPC for arsenic at sediment core location SC02 is uncertain due to one elevated arsenic detect (1,600 mg/kg in the 0 to 1 foot depth interval) compared to the remainder of the data set. This uncertainty is also applicable to SO soils due to sampling location SO-13 (2,680 mg/kg in the 8-foot interval), sediments at Station 13/TT-27 due to sampling locations SD-13-01-FW and SD-13-02-FW (4,210 mg/kg and 2,480 mg/kg), sediments at Station WH due to sampling location SD-12-01-ME (3,230 mg/kg), and sediments at Station CB-03 due to sampling location CB-03-11 (1,410 mg/kg). This uncertainty may result in either an overestimate or underestimate of risk.

- Even though low-flow sampling techniques were used to collect Northern Study Area groundwater samples, a number of monitoring wells could not be stabilized prior to the collection of groundwater samples. These samples may have contained elevated levels of suspended particulate materials, resulting in an overestimate of the bioavailable contaminant levels in the samples. Risk estimates based on groundwater samples containing elevated levels of suspended solids may overestimate risk.
- Future air EPCs for the industrial and commercial groundwater use scenarios were generated from groundwater data through the use of volatilization and dispersion modeling. Parameter values used in these models were selected to represent reasonable maximum exposures that may occur in the future should groundwater be used as process water or for use in a warm water car wash. The risk associated with future groundwater use may be less than estimated should groundwater uses that result in a lower degree of worker exposures be considered (e.g., use of groundwater for cooling in a closed system).
- The evidence evaluated in the January 2005 Technical Memorandum suggests a limited potential for the migration of arsenic to a future supply well within the Wells G&H IWPA at a concentration above the MCL. There is some uncertainty in the analysis since the study relied on existing data and studies, in a "weight of evidence" approach, to evaluate the possible effects of arsenic and heavy metal contaminated sediment on future potable water development in the Central Area aquifer. If the aquifer is utilized in the future for drinking water purposes, then water quality geochemical parameters (e.g., dissolved oxygen, oxidation-reduction potential) and metals (e.g., arsenic, chromium, lead) should be monitored. Any detected contaminant levels should be dealt with in accordance with current

local, state, and federal policies and regulation, which may include treatment during design, startup, and long-term operation to ensure metals do not impact the production well(s) at concentrations above drinking water standards (e.g., arsenic greater than 10 µg/L). If arsenic does migrate to the production well(s), then treatment options would need to be considered for the extracted water prior to public distribution. Note that treatment may need to be considered regardless due to the elevated levels of manganese present in the aquifer.

6.4 Human Health Risk Conclusions

As identified in the baseline human health risk assessments, the following contaminants, media, and locations exceed risk management guidelines established for human exposures:

Current Scenario

- Arsenic in sediment at Stations WH and CB-03 in the Southern Study Area.

Future Scenario

- Arsenic in sediment at Stations 13/TT-27, WH, NT-3, and CB-03 in the Southern Study Area;
- Arsenic at sediment core locations SC02 in the Northern Study Area and SC05, SC06, and SC08 in the Southern Study Area;
- Arsenic in soil at locations SO-3, SO-11, SO-13, SO-14, and SO-16 in the Northern Study Area;
- Arsenic in groundwater at monitoring wells B7-01, B4-04, B7-02, B6-03, B5-02, and B8-04 in the Northern Study Area;
- Benzene in groundwater at monitoring wells B5-01, W5-06, W5-05, B7-03, B9-02, B9-01, and W5-03 in the Northern Study Area;
- Trichloroethene in groundwater at monitoring wells AE-03, W5-03, AE-02, AE-04, and AE-06 in the Northern Study Area; and
- Naphthalene in groundwater at monitoring well W5-05 in the Northern Study Area.

Benzo(a)pyrene was also a minor risk contributor at sediment stations 13/TT-27 and WH. However, the benzo(a)pyrene sediment concentrations at these stations fall within the range of concentrations detected at the reference stations. Pentachlorophenol, 1,2-dichloroethane, chloroform, and methyl

tert-butyl ether were also identified as minor groundwater risk contributors in the Northern Study Area.

Based on the City's February 2005 draft redevelopment plan, future reuse plans are not anticipated for the interior wetlands represented by Station NT-1 (nature trail with wetland board walk) and NT-2 (nature trail with wetland pier). Hence, sediment exposure pathways for NT-1 and NT-2 are currently considered incomplete, and have not been included in the above listing of locations exceeding risk management guidelines. If necessary, these decisions will be further reviewed upon finalization of the City's redevelopment plan.

The migration of arsenic-contaminated surface water from the HBHA in the Northern Study Area to depositional areas of the Southern Study Area (i.e., the Wells G&H 38-acre wetland and the former cranberry bog) contribute to the human health risks and hazards above risk management guidelines observed at sediment stations 13/TT-27, WH, NT-3, and CB-03 in the Southern Study Area.

7.0 BASELINE ECOLOGICAL RISK ASSESSMENT SUMMARY

Baseline Ecological Risk Assessments have been prepared for the Northern and Southern Study Areas of the MSGRP RI by Metcalf & Eddy, Inc. for USEPA Region I. The Southern Study Area Risk Assessment, entitled “*Baseline Human Health and Ecological Risk Assessment Report, Wells G&H Superfund Site, Aberjona River Study, Operable Unit 3*” was released by USEPA in September 2004 (M&E, 2004). The Northern Study Area Baseline Ecological Risk Assessment is contained within Appendix 7 of this report. This section of the MSGRP RI provides a comprehensive summary of the Northern and Southern Study Area Baseline Ecological Risk Assessments.

The two risk assessments comprehensively evaluate the area from the Industri-plex Superfund Site to Interstate 95/Route 128 (Northern Study Area; Reach 0) and from Interstate 95/Route 128 south to, and including, the Mystic Lakes (Southern Study Area; Reaches 1 through 6). Significant features of the Northern and Southern Study Areas include the Industri-plex and Wells G&H Superfund Sites, Halls Brook Holding Area (HBHA), Aberjona River, Mystic Lakes and associated wetland areas located north and south of Interstate 95/Route 128 in Woburn and Winchester. The Wells G&H 38-acre wetland is located south of Route 128, extending to Salem Street, and is part of the Southern Study Area.

7.1 Purpose and Approach

The objective of the Northern Study Area and Southern Study Area Baseline Ecological Risk Assessments (BERAs) was to determine whether contaminated media (surface water, sediment, and/or biota) pose risks to ecological receptors. The two risk assessments were prepared using USEPA risk assessment guidance documents and protocols, along with site-specific assumptions applied consistently across the two study areas. The consistent application of methodology across both study areas allows for the formulation and discussion of comprehensive risk results and associated uncertainties applicable to the river as a whole. The comprehensive risk assessment provides a refinement of risks, an evaluation of the ecological significance of risks in the study area as a whole, and determination of unacceptable ecological risks to ecological receptors. The risk assessment results will also be used to identify media, exposure pathways, and chemicals of greatest potential concern.

Based on EPA guidance, each BERA used effects-based screening criteria to identify contaminants of potential concern (COPCs) in each media. Receptor species were selected for exposure

evaluation to represent various components of the food chain in the river/wetland ecosystem. Since habitats and exposure pathways were similar in the two study areas, receptor species/communities selected for evaluation were similar, and included: muskrat, green heron, mallard, the short-tailed shrew, benthic invertebrates, and several species of warmwater fish. In addition, in the Northern Study Area, a piscivorous mammal, the river otter, was also evaluated. The exposure models used similar exposure factors and assumptions so that comparisons can readily be made between risk results from the two BERAs. The exposure estimates for each receptor species or community were evaluated based on spatial scales representative of the home range of each species. Details of the COPC screening, the selection of assessment and measurement endpoints, exposure assumptions, risk characterization, and uncertainty analysis are provided in each of the BERAs. Summaries of risk by media and receptor are provided in the following section.

7.2 Media-Specific Risk Refinement Summary

The following presents a discussion of the results of the risk assessments, organized by medium and receptor/endpoint. For both study areas, the risks identified for each receptor are reviewed with consideration of the level of the risk to the population or community, the uncertainty associated with the analysis, and the amount and quality of the affected resource. The results are interpreted further within the context of the magnitude of the effect, the uncertainty of the estimates, and the ecological significance of the effect. Overall summaries of estimated risks are presented for each receptor species or community in Table 7-1. Figure 7-1 presents the results of the risk assessment by habitat area and receptor population or community.

Each endpoint has associated with it a magnitude of risk and a degree of uncertainty. The magnitude of risk incorporates both the degree to which the endpoint was exceeded and also the proportion of the habitat affected. Since the endpoints were based on populations effects, a reasonable probability of risk was determined to be present only when a risk was present through the majority of the organism's habitat. The ecological significance related to each receptor/endpoint is evaluated in terms of factors defined by USEPA (1997). An evaluation of these factors is used to clarify if risks associated with contamination are present at levels that represent unacceptable ecological risk. Each of these six categories evaluated in Table 7-1 are briefly described below.

- **Endangered or sensitive species.** Since no endangered, rare or threatened species were identified in the study area, there was no risk to protected species in the study area.

Similarly, none of the receptor species were used as a surrogate for a particularly sensitive species that might be similarly affected by exposure to contamination in the study area.

- **Magnitude of the effect and level of biological organization affected.** The magnitude of the effect is level of risk measured in the evaluation of the assessment endpoints. The magnitude of the effect considers the areal extent of the receptor's habitat represented. The ranking of this effect in Table 7-1 reflects the level of risk for each receptor species as identified in the right-hand portion of the table. The uncertainty of the risk estimate is considered in the evaluation of this factor. The level of organization affected is related to whether the risk is to individuals, populations, or communities. Other influences on the population, including recruitment, were also considered.
- **Likelihood the effect will occur or continue.** The likelihood that effects will occur or continue is related to both the uncertainty of the risks to the receptors and the ability of the contaminants to bioaccumulate or biomagnify into the food chain. A major part of the uncertainty for each receptor is the bioavailability of the forms of arsenic in the diet. Arsenic may continue to persist in the environment (see last bullet), however arsenic is not known to bioaccumulate in biota and has low trophic transfer potential. Based on these considerations, the likelihood of the effect to occur or continue is ranked as low.
- **Relative importance of the affected area to the surrounding habitat.** The relative importance of the receptor's habitat affected by the potential impact relates to the ecological relationship of the affected area to the surrounding habitat. Its importance to the functioning of the surrounding habitat is related to the ability to serve as a nursery, wildlife migration corridor, or overwintering habitat, etc.
- **Extent to which the affected area is highly sensitive or ecologically unique.** The degree to which the affected area itself (directly) represents highly sensitive or ecologically unique (essential) habitat to the receptor population is related to the quality of the habitat based on factors other than contaminant concentrations. These include physical structure, vegetative community structure and diversity, size of the contiguous habitat area, and uniqueness of the habitat in the local environment. These habitat characteristics relate to the quality of habitat for each receptor species in terms of serving as foraging, breeding, or nursery areas.

- **Recovery potential of the affected receptor and chemical persistence.** The recovery potential relates to the likelihood an affected receptor will not recover from the effect of site releases, and also to the persistence of the chemicals in the environment. For example, the arsenic concentrations in sediments will likely be persistent, and other than reduction in concentrations due to transport downstream or deposition of material with lower arsenic concentrations, total arsenic concentrations are not expected to change over time. Species are less likely to recover from an effect of exposure if it has a long generation time or limited foraging range, resulting in more intense exposure of individuals.

The magnitude of the potential risk was considered in evaluating the significance of each factor; a receptor with low risk generally shows a low ecological significance in all categories (Table 7-1).

Based on the analysis of the nine selected indicators/endpoints in the two BERAs, there were no indications of significant ecological risk associated with VOC, SVOC, and pesticide/PCB contamination within the combined study areas, with the exception of potential risk to aquatic receptors from benzene in the deep water of HBHA Pond. Evidence suggests that there is high exposure to inorganic COPCs, especially arsenic, for benthic invertebrates, semi-aquatic mammals, bottom feeding fish, and small forage fish in the study area. In general, the resulting level of ecological risk for the receptors is low, except for the benthic invertebrate community in the HBHA Pond. The magnitude of the risk and uncertainty associated with the ecological effects for each receptor is discussed below.

7.2.1 Surface Water

COPCs were identified in the initial surface water screening. Among the COPCs in surface water, benzene was detected in deep samples from HBHA pond. The average concentration in deep samples indicated potential risk based on Tier II benchmarks. SVOCs were infrequently detected and represent a low risk to receptors in surface water throughout the combined study areas. Average inorganic COPC concentrations, including barium, cadmium, cobalt, manganese, silver, and zinc, exceeded surface water benchmarks in the Northern Study Area. Seven were detected at concentrations above screening values in the Southern Study Area including barium, cadmium, copper, iron, lead, mercury, and silver. Based on the low magnitude and frequency of the exceedances of National Ambient Water Quality Criteria (NAWQCs) and screening benchmarks, the risk to aquatic organisms in the study area from exposure to metals in surface water is low. Surface water screening indicated a possible risk from exposure to benzene in HBHA Pond, based on data

utilized in the BERAs. Additional data collected as part of a Natural Attenuation Study (Ford, 2004 and Ford, 2005), documented high concentrations of benzene at depth in the HBHA Pond in April 2000 and 2001 and September 2004 (maximum 2,530 µg/L).

The USEPA acute NAWQC for dissolved arsenic is 340 µg/L and chronic NAWQC for dissolved arsenic is 150 µg/L (USEPA, 2002). These values were derived by EPA for arsenic III, but are applied to total arsenic. Speciation in HBHA Pond indicates that the majority of the arsenic is in the form of Arsenic III. The maximum dissolved arsenic concentration measured in surface water in the combined study area (120 µg/L) was below the NAWQC. Additional surface water data were collected from the HBHA Pond to evaluate arsenic contamination within the Industri-plex Superfund Site and the GSIP Study Area as part of a Natural Attenuation Study (Ford, 2004). These data indicate very high concentrations of dissolved arsenic in the deep water of the HBHA Pond during sampling in September of 2001. These values, up to 5,043 µg/L, greatly exceed the acute NAWQC.

EPA (Ford, 2004) data indicate that these high values are most likely associated with sediment dissolution of arsenic to the over-lying water column. The high concentrations of dissolved arsenic in the deep water of HBHA Pond represent a risk to aquatic receptors. As the current conditions in the deep water of the pond, including long periods of anoxic conditions, limit the deep water are for fisheries habitat, exposure of fish to these conditions of high dissolved arsenic is limited. The risk from exposure is to aquatic invertebrates in the deep water at the sediment-water interface.

Downgradient of the HBHA Pond, the surface water concentrations were below NAWQC and were well below those expected to cause effects on fish. However, as described below, further analysis of the potential risk from exposure to surface water was conducted through food chain modeling, as well as evaluation of fish exposure through analysis of tissue COPC concentrations.

7.2.2 Sediment

Risks from exposure to sediment-related contaminants were evaluated first by screening sediment concentrations against sediment quality benchmarks. The effects of sediment contaminants on sediment-dwelling benthic invertebrates was the subject of extensive further analysis in both BERAs, including toxicity testing, invertebrate tissue analyses, and benthic invertebrate community studies. The combined results are summarized below. In addition, the indirect effects on other receptors exposed to incidental sediment ingestion or ingestion of biota exposed to sediments was address in the food chain models, with combined study area results presented in Section 7.2.4.

An evaluation of the benthic invertebrate measurement endpoints indicates that there are impacts from inorganic contaminants on invertebrate communities within the study area. The comparison of sediment concentrations to effects-based benchmarks indicate that there are potential effects on benthic communities from inorganics, especially arsenic, cadmium, chromium, copper, lead, mercury, and zinc in both study areas, with highest sediment metals concentrations observed in Reach 0 (the Northern Study Area) and Reach 1. Calculation of PEC quotients for stations in the Northern Study Area (Appendix 7A, Section 5.2.3) confirmed the high exceedances of sediment quality benchmarks, and the relatively high contribution of arsenic to the PEC quotient.

Both of the BERA data sets were used to evaluate the relationship of sediment contaminant concentrations and benthic invertebrate toxicity testing results. In the Northern Study Area, there was evidence of acute toxicity to benthic organisms at deep stations in HBHA Pond. The data also presented strong evidence of toxicity to invertebrates at Station MC-06 in the shallow area of HBHA Pond. Downstream in the HBHA wetlands, evidence of invertebrate toxicity was also observed for Stations SD-MC-10 and SD-MC-11, however the number of endpoints statistically significant from controls were limited. Toxicity data indicated potential effects from exposure to sediments at these stations. The toxicity testing results were highly correlated to sediment arsenic concentrations, particularly when the effect of high iron concentrations was taken into account. In the Southern Study Area, toxicity testing results showed small reductions in growth of laboratory test organisms that corresponded to the concentration of arsenic in sediments (M&E, 2004). Although the concentration of a number of metals co-varied with the elevated concentration of arsenic, toxicity results were most consistently associated with high arsenic concentrations. Similar to the analysis in the Northern Study Area, the toxicity endpoints (survival and growth of laboratory test organisms) showed a correlation of sediment arsenic concentration to growth of *C. tentans* and *H. azteca* among the Southern Study Area samples. This relationship was improved when the potential arsenic toxicity was represented by the ratio of arsenic:iron (As:Fe) in sediments (Appendix 7E). The As:Fe ratio represents the ameliorating effect of high iron concentrations on arsenic toxicity. However, the strength of the correlation to toxicity endpoints to As:Fe concentrations is not as strong as observed among the Northern Study Area data, due to the lack of samples with high toxicity in the Southern Study Area as compared to the results observed from HBHA Pond.

The benthic invertebrate tissue data also add to the weight of evidence for the effects of arsenic, as the concentration of arsenic in invertebrate tissue exceeded ecological effects levels and were greatly elevated at Station MC-06. In general, elevated concentrations of metals in invertebrate tissue corresponded to locations with high toxicity, but showed less association with concentrations

of the same metals in downstream sediments. These results indicate that the toxicity and impairment to benthic invertebrates in HBHA Pond is likely related to the forms of metals in the sediment having higher toxicity and bioavailability than the same metals present in sediments downstream. Invertebrate tissue data in the Southern Study Area were limited to crayfish, and did not show significant increases of metals concentrations in study area samples compared to reference locations.

Community composition data indicated highly impaired benthic community with low abundance and diversity in the sediments of HBHA Pond in deep water. In the shallow area of HBHA Pond, the community indices showed evidence of impairment with limited number of taxa, low diversity, and high dominance of pollution-tolerant oligochaetes. In the Southern Study Area, severe impairment of communities was not observed, but a reduction in diversity and an increase in dominance of oligochaetes and chironomids was observed in stations with higher arsenic concentration, particularly at Station 10. Results in both of the BERAs indicated some patterns of community impairment associated with contaminant distributions, as well as effects of other habitat variables (hydrology, depth, dissolved oxygen concentrations) on the species composition and abundance of benthic invertebrates.

Subsequent to the BERAs, a supplementary analysis of the benthic community data was conducted for the data sets from the combined study areas, to evaluate patterns of community composition along environmental gradients, as well as contamination gradients among all of the benthic community samples. The results of the multivariate statistical analysis of these data are summarized in Appendix 7D. The purpose of the analysis was to further evaluate the relative significance that contaminant concentrations in sediments have on the benthic invertebrate community in the combined study area. Environmental variables included physical and chemical measurements made during the survey, as well as sediment concentrations of contaminants of concern.

The results showed that based on the community composition of the benthic invertebrates in the sediments, the two samples from the deep water of HBHA Pond were dramatically different from all of the other samples, with very low abundance and species richness (one species in each). Based on multivariate analysis of community composition, the strongest factors affecting the invertebrate community were AVS content of the sediment, depth of the sampling location, dissolved oxygen in the overlying water, and the habitat characteristics (flow) of the location from which the sample was collected. When the effects of these environmental variables are accounted for using canonical correspondence analysis (CCA), the results show a portion of the community structure is strongly

correlated to sediment arsenic:iron ratio ($r = 0.874$, $p < 0.001$, Appendix 7D). Stations with high arsenic concentrations, but with high iron as well, have lower toxicity due to the effect of iron to bind arsenic in less toxic forms. The availability and toxicity of arsenic in HBHA Pond is unique due to the strongly reducing conditions in the deep water. Release of dissolved arsenic at the sediment-water interface as documented by EPA (Ford, 2004), at concentrations well above NAWQC values, support the conclusions that the absence of invertebrates is related to contamination in the sediments of the pond.

The levels of contaminants observed outside of HBHA Pond correspond to detectable but small changes in community composition correlated to contaminant concentrations in the sediment, particularly with arsenic:iron ratios. The analysis indicates that the benthic community shows some shifts in community composition which is associated with the bioavailable fraction of arsenic in the sediment (represented by the As:Fe ratio). The community analyses also support the conclusions that the community structure at the two deep stations in HBHA Pond are uniquely impaired and dissimilar to other study area and reference stations.

Considering each of the lines of evidence for the benthic invertebrate endpoint, the data indicate that, within HBHA Pond, there is severe impairment of the benthic invertebrate community. Although other factors, including dissolved oxygen, could contribute to the observed absence of invertebrates in the deep water, the laboratory toxicity testing results clearly indicate toxicity of these sediments to invertebrates. The laboratory toxicity results cannot distinguish between the relative toxicity of the contaminant mix present, which includes arsenic, other metals, and VOCs, such as benzene. However, the toxicity of the sediments to invertebrates in the laboratory was clear, and is supported by the lack of invertebrates to be found in the sediments during the community studies. The high concentrations of metals in invertebrate tissue support the conclusion of high exposure of invertebrates in the sediments to bioavailable forms of inorganics, particularly arsenic.

Downstream of HBHA Pond, in the HBHA Wetland as well as the Southern Study Area, depositional areas with high arsenic show indications of impairment and reduced growth in toxicity tests. These results indicate that the toxicity and impairment to benthic invertebrates in HBHA Pond is possibly related to the forms of metals in the sediment having higher toxicity and bioavailability than the same metals present in sediments downstream. Although the concentrations of arsenic and the arsenic:iron ratios in the sediment are high in some areas of the site downstream of the HBHA Pond, the severity of the impacts on the benthic community are generally low in the downgradient areas. There appears to be a shift in community composition clearly associated with the contamination

gradient, but the magnitude of the impact on community composition is low downgradient of HBHA Pond.

The summary of risk (Table 7-1) indicates difference in the magnitude of the risk to benthic invertebrates between HBHA Pond and the remainder of the combined study area. In HBHA Pond, there is a high risk and confidence in the several supporting lines of evidence that there is severe toxicity and impairment of benthic communities. In the downgradient areas (HBHA Wetlands and the Southern Study Area) the evidence indicates a low magnitude of toxicity, although there was a high correlation of effects with distribution of site contaminants (mainly arsenic).

Benthic invertebrates provide important functions in aquatic ecosystems. They act as a prey base for fish and other consumers. They also have major functions in healthy ecosystems in decomposition and nutrient cycling. The ecological significance of the impairment of benthic invertebrates is related to the loss of these functions. In the wetlands downgradient of HBHA Pond, where, in general, impacts caused some shifts in community composition, the change in the function of the community may not be significant. If preferred prey species are lost, the habitat may become less desirable as a forage area for fish or other species such as waterfowl. However, as the extent of these impacts are not widespread (the number of stations with toxicity and impairment are limited) the ecological significance of the effect is low.

The impact on the benthic community in HBHA Pond, with severe toxicity and impairment of benthic communities, represents a significant ecological effect. The habitat of HBHA Pond (man-made stormwater basin with limited vegetated shallow areas) is not high quality, but the impact is severe and likely affects the majority of the basin. The ecological significance of this effect is rated as moderate (Table 7-1) because the severe impact is confined to HBHA Pond, and not the downstream wetland habitats. The ecological significance is also related to the size and quality of the aquatic resource affected. The level of biological organization affected (benthic community) is high since an impact at the community level was detected. However, the impact (loss of invertebrates) does not have a high intrinsic value, as compared to protection of higher level consumers such as fish, mammals, and waterfowl. The relative importance and the extent to which the area is unique is low, as the effects are isolated to HBHA Pond. The permanence of the effect is also low, in that, if the exposure to the contamination in sediment were removed, invertebrates would quickly recolonize the area. However, due to the magnitude of the adverse effect on this receptor community, the impact on the benthic community in HBHA Pond represents an unacceptable ecological risk.

7.2.3 Soil

Risks from exposure to soil-related contaminants were evaluated first by screening soil concentrations against soil screening benchmarks. As a second step, effects on terrestrial receptors exposed to soil contaminants through ingestion of biota exposed to soils was addressed in the food chain models using short-tailed shrew as the small mammal receptor. The combined study area results for short-tailed shrew are presented in Section 7.2.4.

In the Southern Study Area, the majority of the stations were evaluated as wetland sediments, as the areas were frequently inundated with water. Separate soils screening was not done. All COPCs identified in wetland sediments were evaluated for potential effects on small terrestrial mammals at 19 stations bordering the permanently inundated river/wetland habitats in the Southern Study Area. In the Northern Study Area, surface soil samples were collected at two stations, one at the north end of HBHA Pond (Station A6) and one along the east bank of the HBHA Wetland (Station HB04). Seventeen inorganics were detected at concentrations which exceeded screening benchmarks and were retained as COPCs, including aluminum, antimony, arsenic, barium, cadmium, chromium, chromium VI, copper, iron, lead, manganese, mercury, selenium, silver, thallium, vanadium, and zinc. Each of the COPCs identified in soil were also COPCs in sediment, with the exception of aluminum. Among the inorganics identified in the screening in the Northern Study Area soils, only arsenic was identified as posing a potential effect on shrew (see food chain results, below).

7.2.4 Food Chain

Estimates of dietary exposures for wildlife were quantified for each of the selected receptor species. Dietary exposure models were used to estimate exposure of each receptor species to each of the COPCs identified in the screening of sediment, surface water, and soil data (as applicable) from the study areas. Doses were calculated by summing the ingested dose from drinking water, food items, and sediment/soil that may be incidentally ingested during foraging. COPC daily dose estimates were compared to toxicity reference values (TRVs) to evaluate the effect of exposure on indicator species. Risks to receptors were based on exceedances of LOAEL TRVs for each receptor for an average case exposure scenario over the majority of the habitat of the assessment population within the study area. Based on the dietary modeling, there were negligible risks to green heron from exposure to COPCs in both of the study areas. In addition, there were negligible risks to river otter from exposure to COPCs through dietary exposure in the Northern Study Area. The majority of the diet for both green heron and river otter was based on consumption of fish. Use of site-specific

values for fish tissue concentrations in the study area showed negligible risk to both of the piscivorous receptors. Since the concentrations of COPCs in fish tissue were generally lower in the Southern Study Area, risks to otter in these reaches would also have been negligible (Table 7.1).

7.2.4.1 Mallard

Food chain modeling based on site-specific data indicated negligible risk to mallard duck from exposure to COPCs in the Northern Study Area. For mallard, chromium, lead, and mercury posed low risk in the Southern Study Area, mainly within the Wells G&H 38-acre wetland, resulting from high sediment concentrations of these metals in Reaches 1 and 2. The HQs, based on LOAEL TRVs and site-wide averages for mercury and lead in the Southern Study Area, were less than 1. The HQs for chromium were less than 1 site-wide and equal to 1 for the 38-acre wetland. Although chromium, mercury, and lead may present a risk at individual stations, the risk to waterfowl on a site-wide basis is low. This results in the evaluation of the magnitude of the effect, in terms of ecological significance, is low. The likelihood that high concentrations of sediment metals in limited areas of the 38-acre wetland will have serious population effects on a species with wide foraging ranges, like mallards is low. Although habitat of the 38-acre wetland is considered to be of relatively high quality and local ecological significance, the low probability of impacts on the receptors results in low ecological significance of the effects on waterfowl (Table 7.1). Hence, the impact on the mallard population is not considered an unacceptable ecological risk.

7.2.4.2 Muskrat

In both of the separate BERAs, muskrat exposure modeling was conducted on a station-by-station basis. In Southern Study Area, the highest risks to muskrats were for arsenic exposure in Reach 1 and Reach 2. Based on the BERA endpoint, arsenic was determined to pose a potential risk to muskrat populations based on the large number of stations in Reach 1 exceeding levels of potential harm. These results indicated a likelihood of potential impacts on survival or reproduction of mammal populations such as muskrat exposed to arsenic in the diet while foraging in the Southern Study Area, with a high degree of uncertainty associated with this estimate. In addition to arsenic risks, the potential risk to muskrat from exposure to chromium, copper, lead, and mercury was high only at a few stations, and based on the endpoint criterion, exposure to chromium, copper, lead, and mercury was determined to present a low risk to muskrat and other aquatic mammals. Similarly in the Northern Study Area, arsenic was the only inorganic identified as posing a potential risk to omnivorous mammals, such as muskrat, that consume aquatic vegetation as a large portion of their

diet. The dietary analysis indicates high exposure of muskrat to arsenic in HBHA Pond and upper portions of the HBHA wetland, with uncertain risk due to low confidence in dietary estimates and selection of reference toxicity values representing harm.

The major contributions to uncertainty associated with risk estimates based on the muskrat models, as identified in the BERAs included the TRV used in calculating the HQ, the estimates of the plant tissue concentrations of arsenic and the amount of the plant tissue arsenic that was assumed to be available once ingested by the muskrat. The bioavailability of the plant tissue arsenic was assumed to be 100%, to be conservative, but the actual dose to the animal may be substantially less. As documented in the BERAs, a large source of uncertainty is the selection of a TRV for estimation of HQs. The results of different studies often varied several orders of magnitude, based on using various forms of the COPC, different species, and different endpoints. The LOAEL TRVs for muskrat ranged from 0.55 to 24 mg/kg-d. The range of the HQs calculated for each station in the combined study area using these TRV values is shown in Table 7-2. Using the lowest TRV of 0.55 mg/kg-d (based on 3-year reproduction in laboratory rats), all of the stations, except three in Reach 2, had HQ values above 1. Also using the low TRV, one of the reference stations with a plant tissue arsenic concentration of 2.8 mg/kg had an HQ of 3, indicating that using the TRV is an over-estimation of risk. Alternatively, using a single-study TRV of 24.12 (based on 27 months growth in laboratory rats), only three stations in Reach 1 had HQs greater than one. Each of these stations had sediment arsenic concentrations greater than 1200 mg/kg, and the dose of arsenic from plants was based on the sediment arsenic concentration times an uptake factor. This analysis shows the range of estimated risk using the lowest TRV to the highest; indicating that there is a range of risk from negligible at a few stations to low/moderate at most of the stations in Reaches 0 to 2, depending on the TRV selected.

As a final comparison, a TRV of 2.35 mg/kg-d was calculated from six available laboratory studies with long-term (chronic) exposures, and growth or reproduction endpoints (Table 7-3). This TRV was the geometric mean LOAEL, based the method used to calculate mammalian TRV screening values in Ecological Soil Screening Levels Guidance (Eco SSLs guidance, EPA 2003). Using this TRV, 65% of the muskrat exposure points (stations) were calculated to have HQ values above 1; within individual reaches, 80% of the stations in both Reach 0 and Reach 1 had HQs above 1.

As mentioned above, the estimate of the plant dose (approximately 88% of the dietary exposure to muskrats) was associated with additional uncertainty. Plant data were collected at four locations in Reach 0 (Northern Study Area), three locations in Reach 1 (Wells G&H wetland) and at three

reference locations (Table 7-4). To estimate the station-specific plant dose for other stations in the Southern Study Area, a site-specific uptake factor was calculated and applied to the sediment concentration to estimate plant tissue dose (Table 7-2). Results from the stations where plant data were collected are shown in Table 7-4. These stations provide the best risk estimate for muskrat, and using the geometric mean TRV of 2.35, all of the HQs were less than 10, ranging from less than 1 at Station 21 up to an HQ of 7 at Station HB02-1, with the highest plant arsenic concentration of 32 mg/kg. The additional uncertainty of the variation of arsenic in different species of plants and in the portion of the plant ingested (stems/leaves versus roots) were discussed in the BERA for the Northern Study Area (Appendix 7A, Section 6.3). The additional uncertainty in the relative bioavailability to the muskrat upon ingesting the arsenic bound in plant tissue is also discussed in the BERA for the Northern Study Area (Appendix 7A). Based on the muskrat models, both BERAs have concluded potential risk to muskrat from ingestion of arsenic. These risks have been evaluated in the context of the limitations of the data and the models. Within this context the risk to muskrat exceeds levels potentially associated with harm (growth or reproduction), but the uncertainty associated with these estimates are high.

Muskrat have been observed in the study areas, but this fact alone does not conclusively prove the level of the effect on the population, as these individuals may have inhabited only the less contaminated areas, or may have represented recruitment from adjacent habitats. Population studies were not conducted on site for mammals. Quantitative surveys are very unlikely to detect population effects in highly mobile animals such as the muskrat. The results of the BERAs identified potential effects (*i.e.*, chronic impacts) on reproduction or growth. For each BERA, the assessment population was operationally defined to be the population within the study area. The population is regulated by births and deaths (which may be affected by study area conditions) as well as immigration and emigration of individuals from adjacent areas. Severe effects on a receptor could remove individuals from the assessment population, or decrease reproductive rates and cause the study area to serve as a sink for the regional population. In this case, lower reproduction rates within the study area might be compensated by an increase in immigration. The resulting subtle impacts on population density within an urban study area would not likely be detected from field surveys.

The relatively low magnitude of the risk estimates (HQ values less than 10) and the high uncertainty associated with the models leads to a conclusion of low probability of significant population effects on muskrat in the study areas. Even if the areas of highest concentrations of plant tissue arsenic represent substantial risks to individuals, the relative proportion of the habitat affected would not represent a significant reduction in local or regional populations. In considering the significance of

the ecological effects, the amount of wetland habitat in Reaches 0 (Northern Study Area) and 1 (Wells G&H 38-acre wetland) representing risk to muskrat is uncertain. The 38-acre wetland, south of Route 128, is a complex of channels and emergent wetlands. This habitat, although regionally common, represents a relatively large contiguous wetland in the local urban environment. The quality of the habitat varies, but there are large areas of emergent wetland with a mixture of native species, bordered by shrub and forested wetlands, in addition to patches of lower quality *Phragmites*-dominated wetland. The wetlands in the Northern Study Area are narrower, surrounded by commercial/urban uses and dominated by invasive species (*Phragmites* sp.) in many areas. Based on these characteristics, as well as the total acreage represented, the HBHA wetlands in the Northern Study Area are considered to have lower overall habitat value. For this reason, a rating of moderate was given in Table 7-1, characterizing the uniqueness of the wetland habitat across the entire combined study area. The relative importance of the 38-acre wetland and the Northern Study Area to the surrounding habitat is considered moderate, as it may serve as a wildlife corridor and provide a moderately important habitat, regionally, for semi-aquatic mammals. However, based on the data collected, the risk assessment does not provide sufficient evidence to conclude that arsenic contamination in the study areas is causing an adverse effect on muskrat populations that is of sufficient magnitude, severity, and extent that the population will not be maintained in an acceptable state. Hence, the impact on the muskrat population is not considered an unacceptable ecological risk.

7.2.4.3 Shrew

In both of the separate BERAs, short-tailed shrew exposure modeling was conducted on a station-by-station basis. Stations consisted of upland sites, as well as wetland/riparian stations that would be dry enough during a portion of the year for shrew to forage for invertebrates. In the Southern Study Area, the highest risks to shrew were for arsenic exposure in Reach 1 and Reach 2, HQs based on LOAEL TRVs exceeded 1 at three out of 19 stations evaluated. Based on the BERA endpoint, arsenic was determined to pose a low risk to shrew populations based on the small number of stations in Reaches 1 and 2 exceeding levels of potential harm.

Similarly, in the Northern Study Area, arsenic was the only inorganic identified as posing a potential risk to small terrestrial mammals, such as short-tailed shrew, that consume soil invertebrates as a large portion of their diet. The dietary analysis indicates high exposure of shrew to arsenic in the upland surrounding the northern end of HBHA Pond (A6), the upland border of the HBHA Wetlands

(HB02-2 and HB03-3) and upper portions of the HBHA wetland, with low risk due to low confidence in dietary estimates and selection of reference toxicity values representing harm.

The uncertainties associated with dietary modeling in shrew are similar to those discussed for muskrat. The LOAEL TRVs for shrew ranged from 1.19 to 66 mg/kg-d. The TRV used on the BERA models was a relatively low value of 1.5 mg/kg day (TRV based on three generations, reproductive endpoint in laboratory mice). Alternatively, using a single-study TRV of 66 (based on 27 months growth in laboratory rats) no station HQs were greater than one. In addition, a TRV of 6.42 mg/kg-d was calculated from six available laboratory studies with long-term (chronic) exposures, and growth or reproduction endpoints (Table 7-5). This TRV was the geometric mean LOAEL, based on the method used to calculate mammalian TRV screening values in Ecological Soil Screening Levels Guidance (Eco SSLs guidance, EPA 2003). Using this TRV, none of the shrew exposure points (stations) were calculated to have HQ values above 1.

The relatively low magnitude of the risk estimates (HQ values less than 6) and the high uncertainty associated with the models leads to a conclusion of low probability of significant population effects on short-tailed shrew and other small terrestrial mammals in the study area. The available habitat for small terrestrial mammals such as short-tailed shrew is limited to the borders of the wetland. Although the habitat for small mammals may be locally important, the magnitude of the potential effects is low (with high uncertainty), leading to a conclusion of no significant ecological effects related to contaminant exposures to small mammal populations (Table 7.1). Hence, the impact on the shrew populations is not considered an unacceptable ecological risk.

7.2.4.4 Fish

The potential effects of contaminant exposure on fish populations were evaluated through analysis of fish tissue COPC concentrations in both the Northern and Southern Study Areas. In addition, population studies were conducted in the Northern Study Area in order to document the fish community structure at two study area ponds (HBHA Pond and HBHA Wetland Pond No. 3). These locations were compared to two reference ponds (Phillip's Pond and South Pond).

Based on comparison of concentrations of COPCs in fish tissue to reference samples and tissue residue benchmarks, there was no evidence for impacts of COPCs on fish in the Southern Study Area. Tissue concentrations of arsenic in largemouth bass and white sucker in Reaches 2 to 6 were similar to reference values (<0.1 mg/kg arsenic) and did not exceed tissue residue benchmarks.

Whole body tissue data from pumpkinseeds site-wide, were approximately three times higher than reference site values, but average tissue values (0.3 mg/kg arsenic) did not exceed reference toxicity values (0.52 mg/kg) for bluegills. Data from the Southern Study Area were limited in that no samples were collected in Reach 1, due to the limited habitat.

In the Northern Study Area, data were collected in two on-site ponds. Tissue concentrations of arsenic in fish collected in on-site ponds were elevated in comparison to reference locations. Risks were identified to sediment-associated species, primarily white sucker and brown bullhead, based on exceedances of tissue concentrations that may be associated with harm. The magnitude of the exceedances was not high, with HQs of 1.0 to 2.1 (Table 36 of Appendix 7A).

Additional population characteristics of fish in the Northern Study Area were measured to evaluate the health of study area populations. The population data indicated impairment of fisheries; however, the relative influence of poor quality habitat conditions could not be distinguished from impacts associated with toxicity from contaminants. The tissue data provided evidence of potential ecological effects in the Northern Study Area and negligible effects in the Southern Study Area; although population data are inconclusive about the role of toxicity in impairing fish populations in the Northern Study Area ponds. The risks to fish were possibly underestimated based on the inability to discern any impacts from the exposure to toxic substances from impacts associated with the limited and poor overall habitat.

The risks to fish populations documented in the BERAs is located in the Northern Study Area ponds and associated with the high exposure to arsenic. The area of highest exposure and potential impacts is in HBHA Pond and the HBHA Wetland Pond No. 3, which represents an area of relatively low quality aquatic habitat. The value of the potential resource at risk is relatively high, as the affected receptors included populations of several species of bottom feeding and small foraging fish. The magnitude of the risk is low, with uncertainty (Table 7-1) related to the lack of ability to discern impacts associated with contamination from the population studies. Although this endpoint represents a potential impact of relatively high ecological significance, the measured magnitude of the risk is low, and associated with uncertainty. Hence, the overall impact on fish populations is not considered an unacceptable ecological risk.

7.3 Conclusion

Based upon the evaluation conducted under this Baseline Ecological Risk Assessment Summary for the combined study areas, significant ecological risks are present in HBHA Pond within the Reach 0 of the Northern Study Area immediately downstream of the current Industri-plex Superfund Site boundaries. These significant risks were primarily associated with metals contamination, particularly arsenic, in the sediments and their toxicological effects on the benthic invertebrate community. Risk to aquatic organisms are also associated with high observed concentrations of dissolved arsenic in the deep water of HBHA Pond, significantly above NAWQC values; these risks are consistent with the observed impairment of benthic invertebrates in the deep water of HBHA Pond. These significant risks, and contaminant fate and transport contributing to these risks, are considered unacceptable ecological risks to HBHA Pond. Risks to receptors downgradient of HBHA Pond are low. These include low risks to benthic invertebrates and herbivorous mammals, associated with high concentrations of sediment arsenic. These low risks are not considered unacceptable ecological risks to ecological communities in the HBHA Wetlands, Wells G&H 38-acre wetland and Former Cranberry Bog.

8.0 SUMMARY AND CONCLUSIONS

The Industri-plex Superfund Site (Site) is a 245-acre industrial park located in the northeast corner of Woburn, Massachusetts near the intersection of two major interstate highways; I-93 and I-95. The Aberjona River flows through a portion of the Site. Several associated tributaries, drainways, and wetlands also traverse or are situated on the Site.

From 1853 through 1931, the Site was home to various chemical manufacturing operations that principally produced chemicals for the local textile, leather and paper industries; the main products being sulfuric acid and related chemicals. Other chemicals produced at this facility included arsenic insecticides, acetic acid, dry colors, and organic chemicals including phenol, benzene, picric acid, toluene, and TNT. Beginning in 1935, the plant was dedicated to the manufacturing of glue from animal hides until mid-1969 when operations ceased and the site was vacated.

In December 1968, the Mark Phillip Trust (MPT) purchased approximately 149 acres of the property from Stauffer Chemical Company, while others purchased the remaining 35 acres. The MPT intended to develop the Stauffer land, along with land owned to the south and east, as an industrial park to be called "Industri-plex 128". From early 1970 to 1979, development activities involved filling and excavating portions of the property to facilitate the sale of various parcels. Excavations uncovered chemical and glue manufacturing wastes, including decaying animal hides. In addition to two existing waste stockpiles (i.e. East Central Hide Pile and South Hide Pile), some of these waste deposits were excavated and either trucked off site, buried on the southern Boston Edison Company (BECO) right-of-way, or stockpiled in two new waste piles (i.e. West and East Hide Piles).

Development activities also resulted in the filling of wetlands and diverting the course of the Aberjona River. The Halls Brook Holding Area (HBHA) was created as a storm water management area following the filling of Mishawum Lake. The northern portion of the HBHA consists of a large rectangular shallow pond (approximately 175 feet x 900 feet and depth up to 20 feet), referred to as the HBHA Pond. Downstream of the HBHA Pond, the southern portion of the HBHA consist of wetlands containing three smaller ponds. When the HBHA was constructed, the Aberjona River was diverted from Mishawum Lake to its current course which follows a series of culverts and drainage channels in the middle of Commerce Way roadway

that parallels the HBHA approximately 1,500 feet to the east. Flows from the Aberjona River and the HBHA converge at the outlet of the HBHA at Mishawum Road.

The Site was listed on the Superfund Interim List of 115 Top Priority Hazardous Waste Sites in 1981 and on the Superfund National Priorities List in 1983. In 1986, EPA completed a Record of Decision (ROD) that selected a cleanup remedy for the Site that included soil, air, and interim groundwater remedies. The soil remedy consisted of capping arsenic/lead/chromium contaminated soils and hide piles; the air remedy included construction of an impermeable cap and a gas collection and treatment system at the East Hide Pile; and groundwater was to be remediated in the interim through the construction of a treatment system for benzene and toluene “hot spot” areas. Institutional controls were considered a crucial part of the remedy to maintain its integrity into the future. A further investigation of groundwater, surface water, and sediment contamination at the Site and surrounding area was also included in the ROD (entitled Groundwater Surface Water Investigation Plan (GSIP) investigating site-related contamination from Industri-plex Site to Route 128 – Northern Study Area). In addition, EPA was to incorporate this investigation data into a Multiple Source Groundwater Response Plan (MSGRP) RI/FS and determine the need for further remedial actions. In 1989, EPA entered into a Consent Decree with the Settling Defendants and the Industri-plex Site Remedial Trust (ISRT) was established to fund, design, and construct the selected remedy. A second trust, the Custodial Trust, was established to manage and sell, if possible, the land that was included in the settlement agreement by the Mark Phillip Trust.

Around the same time period, an investigation of the Wells G&H Superfund Site, located about 1 mile south of the Industri-plex Site, was being conducted, which included an EPA fund-lead investigation of the surface water and sediment of the southern portion of the Aberjona River to the Mystic Lakes. In 2002, EPA decided to combine the separate surface water and sediment investigations being performed at the two Superfund sites into one study to more efficiently evaluate contamination and risk issues for the entire Aberjona River and ultimately develop one remedial decision for the river, if necessary. As a result, the MSGRP RI Study Area for surface water and sediments was expanded to include the southern reaches of the Aberjona River from I-95-South, through the Wells G&H site, to the Mystic Lakes (i.e. Southern Study Area). It is important to note that the groundwater investigations for the MSGRP RI are limited to the general area surrounding and including the Industri-plex Site. Groundwater in the vicinity of the Wells G&H Superfund Site is currently being investigated, and in some areas remediated, as

part of the Wells G&H Superfund Site cleanup program under the auspices of the EPA and MADEP.

The releases of metals and organic compounds at the Industri-plex Site have resulted in onsite soil contaminant levels that exceed those in background and offsite reference locations. The contaminants gradually dispersed into the surrounding environmental media and have resulted in the contamination of soil, groundwater, surface water, sediments, and biota.

Over 4,800 samples were collected and evaluated as part of the MSGRP RI investigation. Samples were collected from various media including soil, groundwater, surface water, sediment, soil gas, and various biota (both plant and animal). The MSGRP RI Study Area was divided into reaches based on similarity of habitat, species, and accessibility. This concept was first introduced during preparation of the baseline ecological risk assessment for the Aberjona River Study (OU-3) whereby the Aberjona River was divided into six reaches (1 through 6). For purposes of continuity, the same reaches were later used in the human health risk assessment for the OU-3 study and were further expanded with the addition of Reach 0 (i.e. the Northern Study Area) when EPA decided to merge the MSGRP RI and OU-3 investigations. The study area reaches are shown on Figure 2-1 and are generally described as follows:

MSGRP RI STUDY AREA		
NORTHERN STUDY AREA	Reach 0	Industri-plex Site, northern section of Aberjona River, and the HBHA Pond and Wetlands south to I-95.
SOUTHERN STUDY AREA	Reach 1	From I-95, south to Salem Street, including the Wells G&H wetlands
	Reach 2	Salem Street south to the river crossing at Washington Street in Winchester, including the Cranberry Bog Conservation Area
	Reach 3	Washington Street South to Swanton Street, including Davidson Park
	Reach 4	Swanton Street south to Mill Pond in Winchester center
	Reach 5	Mill Pond outlet south to Upper Mystic Lake inlet
	Reach 6	Upper Mystic Lake, including upper and lower forebays, and Lower Mystic Lake to the Mystic River.

The findings of the MSGRP RI are as discussed in the following sections.

8.1 Soil Contamination

The nature and extent of soil contamination was further investigated in areas within, adjacent to, and downgradient of the Industri-plex Site. These areas included soils along the perimeter of the Industri-plex Site boundary, buried sediments of the former Mishawum Lake bed, benzene and toluene source area soils, and floodplain soils along the HBHA and the Aberjona River. Soils impacted by site-related contaminants are as follows:

- There are over 150 acres of soils contaminated with heavy metals, specifically, arsenic, lead, chromium, and to a lesser degree, barium, copper, zinc, and mercury. Approximately 110 acres exceeded the heavy metals threshold values established in the 1986 Industri-plex Site ROD and have been capped with either an engineered cover or with existing materials considered to be “equivalent cover” (e.g. asphalt pavement, building slabs, etc.) Although capped and no longer a threat from erosion, these contaminants remain onsite and represent the most significant source of contamination in the MSGRP RI Study Area. Some of these chemicals have remained adsorbed to soils while others have been mobilized into deeper soils, into groundwater, and into the adjacent wetlands, HBHA and Aberjona River.
- Four areas located outside and adjacent to the Industri-plex Site boundary were investigated to determine if metals contamination exceeding the Industri-plex soil remedy action levels extended beyond the Site boundary. Only the area located between the southern Site boundary and the HBHA Pond (Area 6) was found to contain concentrations of arsenic, chromium, and lead exceeding action levels established for the Industri-plex Site Soil Remedy.
- Prior to its being filled to create open land for development, Mishawum Lake would have served as one of the first significant depositional areas for contaminants being discharged from the Industri-plex Site. Concentrations of VOCs and SVOCs in soils were only sporadically detected in subsurface soils and at low concentrations which did not exceed regulatory screening criteria (i.e. Region 9 PRGs). Soils exhibiting concentrations of metals exceeding comparative regulatory criteria (i.e. Region 9 PRGs and MADEP Soil Background criteria) were detected in both near-surface and subsurface soils. The highest concentrations of metals and most frequent exceedances

for metals, in particular arsenic, generally occurred in the soil samples collected at a depth representing the former lake bottom.

- An investigation was conducted to locate the source of persistent benzene and toluene groundwater contamination located adjacent to the West Hide Pile (benzene) and along Atlantic Avenue (benzene and toluene). This investigation included subsurface geophysical surveys (i.e. ground penetrating radar and electro-magnetic surveys), soil-gas sampling, subsurface soil samples, and groundwater sampling. Although a concentrated source of contamination was not located (e.g. UST, drums, etc.) both benzene and toluene were detected in most soil samples. However, these detections were generally low with the majority of samples well below the comparative screening criteria. At sample locations collected along Atlantic Avenue only 4 of 17 samples exceeded the Region 9 PRGs for benzene (600 µg/kg - residential) and none exceeded the Region 9 PRG for toluene (520,000 µg/kg). In addition, one soil sample collected at the West Hide Pile within the saturated zone, exhibited elevated concentrations of benzene (210,000 µg/kg) exceeding its Region 9 PRG criterion.
- Soil samples were collected in depositional areas along the HBHA and the Aberjona River to investigate the presence of heavy metals deposited by floodwaters. Areas investigated included the banks of a drainage channel along the BECO right-of-way in the southern portion of the Site, floodplain areas along the eastern and southwestern banks of the HBHA, wetlands north of the Wells G&H wetland area at Normac Road, the backyard of a residence located on Salem Street at the southwest edge of the Wells G&H wetland, the Cranberry Bog Conservation Area, Danielson Park, river bank/wetland areas at Kraft Food, Davidson Park in Winchester, and the banks of the Aberjona River near the Wedgemere train station in Winchester. Arsenic was the only metal that was detected in all floodplain sample locations at concentrations ranging from 6.1 mg/kg to 272 mg/kg. Arsenic concentrations exceeded Region 9 PRGs in all areas (except at the Wedgemere station where the criterion was exceeded in seven of nine samples). Although the Region 9 PRG for arsenic (0.39 mg/kg) is based on residential assumptions, approximately 87 percent of floodplain soil samples exhibited arsenic concentrations that also exceeded the MADEP Natural Soil Background reference criterion (20 mg/kg).

8.2 Groundwater Contamination

Between 1990 and 2002 over 460 groundwater samples were collected analyzed and quantitatively evaluated to assess area-wide groundwater contamination in the Northern Study Area. The findings are as follows:

- Arsenic was more frequently detected in groundwater than any other metal (i.e detected in 360 samples out of 467 samples analyzed for metals). Approximately 12 percent of the samples where arsenic was detected exceeded the MADEP GW-3 standard (400 µg/L). Arsenic concentrations were generally highest in the groundwater south and west of the East Central Hide Pile and beneath the BECO right-of-way, with the maximum observed concentration of 24,400 µg/L being located in the BECO right-of-way, just northwest of the HBHA.
- Other metals that were less significantly contributing to exceedances of GW-3 standard included:
 - cadmium: only exceeded in three samples; the highest only slightly exceeding the GW-3 criterion was located just north of the East Central Hide Pile
 - chromium: only exceeded in two samples collected from the same well located approximately 450 feet south of Atlantic Avenue (likely attributed to high suspended solids in the sample)
 - lead: exceeded in 23 samples; all located in the areas north of the Halls Brook Holding Area pond, east of New Boston Road, and west of Atlantic Avenue
 - mercury: exceeded in eight samples sporadically distributed throughout the study area, but the highest concentrations observed were just northwest of the HBHA
 - nickel: exceeded in five samples sporadically distributed throughout the study area but the highest concentrations observed in the area between the East Hide Pile and the East Central Hide Pile

- zinc: exceeded in 11 samples sporadically distributed through out the study area but the highest concentration observed in the area of the Regional Transportation Center
- Benzene was the most frequently detected VOC at concentrations exceeding the GW-2 (2,000 µg/L) and GW-3 (7,000 µg/L) standards. In the shallow groundwater, the highest concentrations of benzene were observed in two areas: between the East Central Hide Pile and the South Hide Piles adjacent to Atlantic Avenue (69,000 µg/L); and within a localized area along the eastern edge of the West Hide Pile (4,100 µg/L). In the deeper groundwater, high concentrations of benzene extended from the southern side of Atlantic Avenue to the southern end of the HBHA Pond. In general, the overall benzene plume, extending in both the shallow and deeper groundwater, is located in the vicinity of Atlantic Avenue south to the HBHA Pond. This current location is generally consistent with the findings of previous investigations conducted during the early GSIP investigations and the 1983 RI.
- Although toluene concentrations did not exceed the GW-2 (6,000 µg/L) or GW-3 (50,000 µg/L) standards for samples collected during the Final GSIP SOW and MSGRP, toluene was detected at elevated concentrations with the center of the plume generally located just south of the Atlantic Avenue/Commerce Way intersection. Elevated concentrations of toluene (up to 2,500 µg/L) were observed in this area. During previous investigations conducted in 1997 by the ISRT as part of the source area investigation, elevated concentrations of toluene were also detected in this same general area with a maximum observed concentration of 19,000 µg/L as well as the intermediate and deeper overburden beneath and immediately south of the BECO right-of-way.
- Trichloroethene (TCE) was observed sporadically in shallow groundwater samples in the vicinity of the BECO right-of way and the HBHA Pond. TCE concentrations did not exceed its GW-2 (300 µg/L) or GW-3 (20,000 µg/L) standards and were generally low concentrations (< 6 µg/L) in the shallow groundwater surrounding the HBHA Pond.
- TCE was also detected at higher concentrations (up to 110 µg/L) in the intermediate to deep overburden in another area approximately 0.5 mile south of the Site, generally located south and southwest of Cabot Road, in the vicinity of former Mishawum Lake.

TCE degradation by-products (1,1-dichloroethene, cis-1,2-dichloroethene) were also detected, but concentrations did not exceed their respective GW-2 or GW-3 standards. Based on the available groundwater data, it appears that the source of the TCE along Cabot Road is not related to the Site.

- Although detected naphthalene concentrations did not exceed GW-2 or GW-3 standards, elevated concentrations were observed in shallow groundwater adjacent to and north of the HBHA Pond.
- Only one semi-volatile organic compound (SVOC), pentachlorophenol, was detected at concentrations exceeding the GW-3 (80 µg/L) standard in the Northern Study Area, at one location within the East Central Hide Pile.
- Samples collected from varying depths at 10 boring locations along the southern perimeter of the Northern Study Area are considered representative of groundwater quality as it leaves the study area and enters the Wells G&H IWPA and were compared to GW-1 standards. Of the metals detected, only arsenic exceeded its GW-1 standard (50 µg/L). No organic compounds were found to exceed their respective GW-1 standards.

8.3 Sediment Contamination

A total of 429 surface sediment samples (0-6 inches in depth) were collected from river, lake, and wetland locations in all reaches throughout the MSGRP RI Study Area during several GSIP and MSGRP investigations from 1995 through 2004. In addition, sediment samples were also collected from local and regional reference stations from areas not expected to have been impacted by site-related contaminants. All sediment samples were analyzed for metals and some were also analyzed for VOCs, SVOCs, pesticides, and PCBs. Metals concentrations observed in sediments were compared to concentrations found at the reference stations and to regulatory reference criteria, such as the EPA Region 9 PRGs and the Ontario Ministry of the Environment and Energy (OMEE) Severe-Effects Level (SEL) sediment quality guidelines.

- The highest concentrations of metals and the most exceedances of reference criteria were found in the HBHA (Reach 0), the Wells G&H wetlands (Reach 1), and the

Cranberry Bog Conservation Area (northern part of Reach 2). The concentrations and frequency of criteria exceedances were generally highest in the HBHA, decreased somewhat in Reaches 1 and 2, decreased further in Reaches 3, 4, and 5, and then increased again in Reach 6 at the Mystic Lakes. The number of metals exceeding reference criteria was highest in Reach 1, followed by Reaches 2 and 0.

- Arsenic was the most prevalent metal that exceeded reference criteria in all reaches. Other metals where more than 50 percent of the samples exceeded all the reference criteria included iron and lead. These exceedances, by reach, are summarized below:

	REACH						
	0	1	2	3	4	5	6
Arsenic							
Lead							
Iron							

Exceeds all reference criteria in >50% of all samples

- Twenty VOCs were detected in study area surface sediment samples. Most compounds were detected infrequently and at low concentrations. Only four compounds (benzene, tetrachloroethene, trichloroethene, and vinyl chloride) exceeded the EPA Region 9 PRGs for residential soil in at least one sample. Benzene exceeded its PRG standard (600 µg/kg) in one sample in Reach 0. Tetrachloroethene, trichloroethene, and vinyl chloride exceeded the PRGs in two, five, and one sample, respectively, in Reach 1. These four VOCs also exceeded all applicable reference criteria in at least one sample. These exceedances occurred at seven locations in Reaches 0 and 1. No samples from the rest of the study area contained VOCs at concentrations that exceeded all applicable criteria.
- Twenty three SVOCs, primarily PAHs, were detected in study area surface sediment samples. The highest concentrations of SVOCs were generally found in Reach 3 and the highest frequencies of exceedance of reference criteria were found in Reaches 0 and 3. Five PAHs [benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, dibenz(a,h)anthracene, and indeno(1,2,3-cd)pyrene] exceeded Region 9 PRGs in all study area reaches, and the reference stations. Benzo(b)fluoranthene concentrations exceeded all

criteria in at least one sample from every reach. Bis(2-ethylhexyl)phthalate exceeded all criteria at only one location in Reach 0.

8.4 Surface Water Contamination

Beginning in May 2001 and ending October 2002, an extensive 18-month surface water monitoring program was conducted throughout the watershed that included measurements of precipitation, streamflow, suspended sediment, and metals concentrations (dissolved and total), in addition to other physio-chemical parameters at 10 stations located along a 9-mile reach of the Aberjona River (see Figure 2-5). The intensive monitoring period captured monthly baseflow sample data as well as six storm events spanning multiple seasons (spring, summer, and fall).

- Concentrations of metals in surface water only sporadically exceeded Ambient Water Quality Criteria (AWQC) at Stations 1-8 during both base flow and storm flow conditions. No exceedances of AWQC criteria were observed at Station 9 or 10 (Mystic Lakes) at any time. The most frequently detected metals exceeding AWQC CCC (chronic) criteria included, aluminum, copper, lead, and zinc. Although the concentrations of arsenic were below AWQC criteria (except one storm event sample collected at Station 4 exceeding the AWQC CCC), both dissolved and particulate phases of arsenic represent potential impacts to downstream depositional areas. For the majority of the 10 surface water sampling stations, the total arsenic concentrations were highest during storm flow conditions.
- The surface water monitoring data showed that metals transport is highly impacted by total suspended solids (TSS) concentrations. Spikes in metals concentrations are associated with spikes in TSS. Monitoring data collected during baseflow conditions show that arsenic concentrations are higher within the northern portion of the MSGRP RI Study Area in the HBHA. This trend was also observed for the other metals evaluated (chromium, copper, iron, lead, and mercury).
- The highest concentrations for metals were most often observed at the outlet of the HBHA (Station 4). Spikes in metals concentrations at this station were associated with spikes in suspended sediment concentrations indicating that elevated levels of metals at this station are associated with the particulate phase. The total metals concentrations

typically decreased downstream of Station 4. During storm events, the highest arsenic concentrations were observed at the outlet of the HBHA Pond (Station 2). The chemocline within the HBHA Pond becomes unstable during large storm events causing high concentrations in the deep surface water to mix with shallow water, and higher concentrations of arsenic to be released at the outlet.

- The reduction of metal concentrations observed during baseflow conditions between Station 4 and at Station 5 and subsequent downstream stations indicates that deposition is occurring between stations. Sediment samples were collected at significant deposition areas along the HBHA and Aberjona River from the Industri-plex Site to the Mystic Lakes. The distribution of arsenic and other metals along the river shows a clear pattern of metals transport from the northern part of the river and watershed originating at the Industri-plex Site, south to the Mystic Lakes with the greatest area of sediment deposition occurring at the Wells G&H wetland and areas north.

8.5 Fate and Transport of Key Contaminants

Past storage, manufacture, and handling practices of numerous chemicals at the Industri-plex Site has resulted in the release of chemicals to Site soils of VOCs (aromatic hydrocarbons), SVOCs (including phthalates, phenols, and PAHs), and metals. Depending on the combination of Site-related contaminants, geologic and hydrogeologic conditions, and surface features, contaminants released to Site soils have migrated into other environmental media, specifically the underlying groundwater, adjacent surface water bodies, and sediments.

The fate and transport of contaminants evaluated in the MSGRP RI involve complicated and interdependent processes that affect mobilization of contaminants between various media and from reach to reach with the MSGRP RI Study Area. The principal source of contamination within the MSGRP Study Area is the capped soils underlying the Industri-plex Site. These contaminated soils are impacting groundwater, which in turn discharges to the HBHA Pond and wetlands and northern portions of the Aberjona River, subsequently impacting surface water. The surface water flows from the HBHA and Aberjona River combine at Mishawum Road and represents the primary contaminant transport vehicle for downgradient receptors. While the applicable fate and transport processes are generally the same throughout the Study Area, the

impacted media and contaminants of concern vary from the northern portions of the Study Area to the lower portions of the Study Area and are summarized as follows:

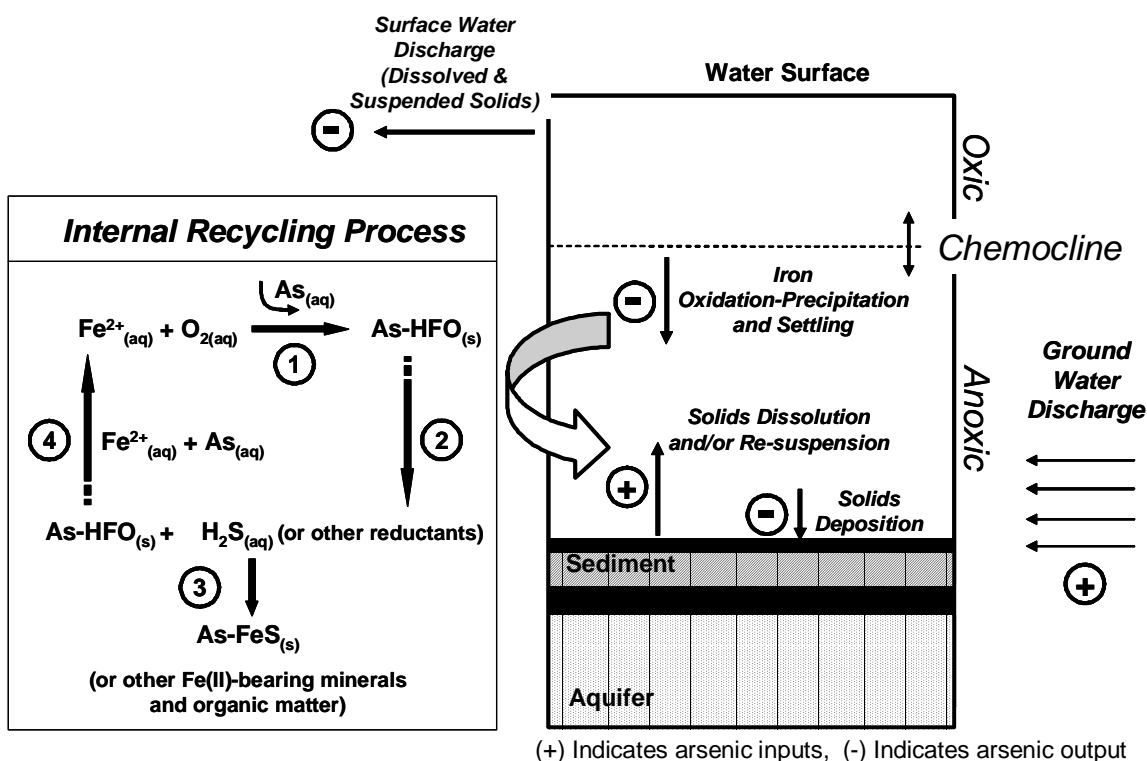
FATE & TRANSPORT MODEL AREA	IMPACTED MEDIA	CONTAMINANTS OF CONCERN
Reach 0 (Industri-plex Site and the HBHA)	Soils, Groundwater, Sediment, Surface water	VOCs, SVOCs, Metals
Reach 1 (38-acre Wells G&H wetland)	Sediment, Surface water, Groundwater	Metals
Reach 2 to Reach 6 (Cranberry Bog Conservation Area to the Mystic Lakes)	Sediment, Surface water	Metals

- The most significant ongoing transport process for metals in soils underlying the Industri-plex Site is leaching to groundwater. Once in groundwater contaminants continue to migrate via advection, diffusion, and dispersion processes. The contaminants most widely detected in groundwater include arsenic, benzene, toluene, and to a lesser degree lead and zinc. Contaminants are then transported through groundwater flow paths and are predominantly discharged in the northern portions of the HBHA Pond, impacting sediments and surface water.
- Portions of groundwater flow at greater depths continue to flow parallel to the main buried valley. As evidenced by downgradient groundwater sample data, the deeper portion of the aquifer does not appear to be a significant pathway for contaminant migration as contaminant concentrations are not being sustained. These contaminants are likely being attenuated by biological and chemical degradation, dispersion, and diffusion processes that are significantly influenced by geochemical conditions.
- Organic compounds in groundwater, such as benzene, discharging into the sediment and deeper portions of the HBHA Pond are generally attenuating to very low concentrations or are not detected in shallow portions of the HBHA Pond surface water. The VOCs in sediments may be biodegraded, partition to surface water, or remain bound to the organic matter present in stream sediments. VOCs that enter into surface water can volatilize into the ambient air where they are degraded by photolysis or hydrolysis; remain in surface water and undergo degradation processes such as

biodegradation, hydrolysis, or reduction-oxidation reactions; or become attenuated through dilution, diffusion, and advection. A study conducted by MIT in 2000 concluded that biodegradation at the anoxic/oxic interface was the largest sink for benzene in the HBHA Pond as compared to other fate and transport processes.

- Available data indicate that because of biological activity occurring in VOC-contaminated soils (most probably degradation of aromatic hydrocarbons [benzene and toluene] or natural organic carbon from the wetland deposits as well as the degradation of waste animal hides located in the hide piles and BECO right-of-way), a reducing environment has been created at the Industri-plex Site. In turn, metals such as arsenic and iron, are being reduced, rendered more soluble, and therefore, much more mobile in groundwater. These actions are evidenced by observed groundwater arsenic levels as well as the presence of arsenic in surface water samples collected in the groundwater discharge zones in the HBHA Pond.
- A fraction of the dissolved arsenic being discharged from groundwater in the HBHA Pond sediments becomes bound to ferric oxides and effectively removed from the water column and become part of the sediment load. However, a portion of the dissolved arsenic continues to migrate through the sediments, diffusing further into the water column whereby the arsenic can either be further sequestered from solution during oxidation and precipitation of ferrous iron at the oxic-anoxic interface or be transported downstream. These reactions are dependent upon a fairly stable chemocline that is present at a depth of 9 to 15 feet, or about mid-way to the bottom of the HBHA Pond. The chemocline is induced by the difference in specific conductance between oxic surface water and anoxic contaminated groundwater, and steady inputs of oxygen, iron, sulfates, and organic carbon. The relative position of the chemocline fluctuates throughout the year due to seasonal variations in temperature and surface water flow. Below the chemocline in deep surface water, high concentrations of dissolved arsenic (up to 5,043 µg/L), benzene (up to 2,530 µg/L), and high conductivity were present in the HBHA Pond. Sudden increases in flows, as seen during storm conditions, mix the water column and break down the chemocline thus allowing more arsenic to be “flushed” downstream. However, the chemocline has been shown to be re-established within a period of less than a month due to the continuous flux of high specific conductance groundwater derived from the Industri-plex Site.

- The basic chemical reactions controlling arsenic distribution and recycling between the sediments and the water column in the HBHA Pond are depicted in the following fate and transport schematic. Processes that remove arsenic from the HBHA Pond water column are indicated with minus signs (including discharge to the downgradient wetland and ultimately, the Aberjona River. Maintenance of a relatively stable chemocline is important to the applicability of the reaction scheme in the diagram.



- Once in the surface water column, as either dissolved or associated with the suspended solid load, arsenic will continue to migrate downstream with the flow of water. Depending on the geochemical and flow conditions, dissolved metals in the water column may absorb to suspended solids, such as fine grained soil particles or other metal complexes and either precipitate and become part of the sediment bed load or be transported within the water column as part of the suspended solid load and be deposited at locations downstream.

- As part of the sediment bed load and depending on the geochemical conditions, metals may dissolve from the sediment particles back into the surface water, whereby the cycle of dissolution and precipitation would continue. This cycling was mostly observed within portions of the HBHA that exhibited significant anoxic/reduced conditions, specifically, within the HBHA Pond. However, whereas wetlands in general typically exhibit reduced conditions or present a significant source of sulfides under oxic conditions, this cycling may be occurring at other portions of the HBHA, but likely at a lesser degree than the HBHA Pond due to its unique geometry and influx of anoxic groundwater.
- Due to its proximity to the Lower South Pond and wetlands, groundwater along the eastern edge of the West Hide Pile, where another source of benzene was detected, is likely discharging to the surface water of the adjacent pond and wetland areas as evidenced by the absence of benzene in groundwater samples downgradient of the West Hide Pile. Once discharged to the sediments and surface water, the benzene is likely being attenuated by biodegradation, chemical degradation, volatilization, and dispersion as seen in the HBHA Pond.
- Surface water data collected from Halls Brook indicate that during storm events, slightly elevated concentrations of chromium and lead are also flowing into the HBHA Pond. However, only lead exceeded its AWQC CCC (i.e. chronic) criterion (2.5 µg/L) during both storm event and baseflow conditions. The source for this contamination is likely the New Boston Street Drainway and the East Drainage Ditch based on surface water quality samples collected during construction of the remedy and sediment data collected during this investigation. Historically, Olin Chemical Corporation has been identified as a source of chromium contamination in sediments along the East Drainage Ditch, a small tributary to Halls Brook.
- An evaluation of contaminated river sediments potential impact to groundwater in the wells G&H wetland concluded that the arsenic in the river and wetland sediments and surface water would not adversely affect the development of large-capacity potable water supply wells in the Wells G&H Central Area aquifer. This conclusion was based on historical water quality data from municipal Wells G and H; information regarding the hydrologic relationship between the aquifer, the river and the wetlands; geochemical conditions existing in the aquifer; recent water quality data from the sampling of various

monitoring wells and surface water stations during site investigations; and known and postulated geochemical behavior of the contaminants and associated metals, notably iron and manganese. These results suggest that arsenic in the river and sediments is unlikely to migrate to drinking water supply well(s) above its current drinking water standard (i.e. MCL) (also refer to Appendix 5B).

- Based on the surface water data, surface water clearly is the transport mechanism that is facilitating arsenic (and other metals) transport through the river system downstream of the Industri-plex Site. This fate and transport mechanism is demonstrated by the baseflow and storm flow surface water sample data collected during the 18-month investigation and is also evidenced by sediment data collected throughout the Aberjona River. Based on these data, the highest concentrations of arsenic are in the northern part of the MSGRP RI Study Area in Reach 0 and steadily decrease as the river flows south through Reach 1-6. Concentrations of arsenic and other metals in surface water at the furthest downstream monitoring stations, located at the Mystic Lakes, show further reductions in metals concentrations, as well as TSS concentrations, during both baseflow and storm flow conditions.

8.6 Human Health and Ecological Risks

The data collected during this investigation were evaluated for potential human health and ecological risks. Separate baseline risk assessments were completed for the Northern Study Area and the Southern Study Area to determine whether contaminated media (surface water, sediment, sediment cores, soil, groundwater, and soil gas) pose risks to human and ecological receptors. The results of the human health and ecological risk assessments have been evaluated and combined into a comprehensive risk evaluation for the Industri-plex Site and the entire Aberjona River. The risk evaluations are more thoroughly discussed in Sections 6.0 and 7.0 of this report and are summarized below.

8.6.1 Human Health Risks

For the purposes of the human health risk assessments, the Northern and Southern Study Areas were divided into stations, defined as areas of recreational use (e.g., wading or swimming) along the Aberjona River, Mystic Lakes, HBHA, and associated wetland/floodplain

areas at which human exposures to multiple environmental media (i.e., soil, sediment, and surface water) may occur. Additional areas containing residual soil contaminants (e.g., the former Mishawum Lake bed) were also evaluated. Northern Study Area groundwater was comprehensively evaluated for potential direct (e.g., industrial use) and indirect (e.g., subsurface migration to indoor air) contaminant exposures.

Prior to completion of the human health risk assessments, EPA completed an arsenic bioavailability study to assist in the quantification of sediment risks (see Appendix 6K), which determined that site-specific arsenic is absorbed less efficiently from sediment than from a water medium. Based on this study, the relative bioavailability estimate was used to quantify sediment ingestion risks. In addition, site-specific chromium VI (hexavalent chromium) data for sediments (for the Northern and Southern Study Areas) and soils (for the Northern Study Area) were collected and used in the risk assessments to more accurately characterize sediment and soil risks at the study areas (see Appendix 6F). The 95% Upper Confidence Limits (UCLs) were calculated using USEPA's software program ProUCL version 3.0, and used as exposure point concentrations (EPCs) whenever possible.

The potential non-carcinogenic hazards and carcinogenic risks for the central tendency (CT) and reasonable maximum exposure (RME) cases were estimated. Overall summaries of estimated carcinogenic risks and non-carcinogenic hazards are presented in Tables 8-1 through 8-4, for sediment, sediment cores, soil, and groundwater, respectively. Figures 8-1 (sediment and sediment cores), 8-2 (soil), and 8-3 (groundwater) depict locations where estimated risks and hazards exceed the USEPA target cancer risk range of 10^{-6} to 10^{-4} and/or a target hazard index of 1 for non-carcinogenic effects. The evaluation of current and potential future surface water, fish, and soil gas exposures did not result in the estimation of carcinogenic risks and non-carcinogenic hazards above regulatory guidelines and are not discussed further. Cumulative receptor risks and hazards, summed across all applicable media, are provided in the Northern and Southern Study Areas baseline human health risk assessments. The areas with human health risks exceeding EPA's target risk range or target hazard index are discussed below, by media.

8.6.1.1 Sediment.

Recreational exposures evaluated included incidental ingestion of and direct dermal contact with sediments. Recreational receptors (young children, teenagers, and/or adults) were selected for evaluation at individual stations after consideration of current and reasonable potential future land use (e.g., residential, park land, or commercial). Based on the City of Woburn's February 2005 draft redevelopment plan, future reuse plans are not anticipated for the interior wetlands represented by Station NT-1 (nature trail with wetland board walk) and NT-2 (nature trail with wetland pier). Hence, sediment exposure pathways for NT-1 and NT-2 are currently considered incomplete, and have not been included in the listing of locations exceeding risk management guidelines below. If necessary, these decisions will be further reviewed upon finalization of the City's redevelopment plan.

Table 8-1 summarizes the recreational risks and hazards at each station. Figure 8-1 shows the locations of the sediment stations associated with current and future risks and hazards in excess of regulatory guidelines.

- For the current scenario, risks and hazards above risk management guidelines were estimated for sediment exposure at Station WH, located near well H in the Wells G&H 38-acre wetland north of Salem Street in Woburn, and Station CB-03, located on the western-central side of the former cranberry bog immediately south of Salem Street.
- For the future scenario, potential risks and hazards above risk management guidelines were estimated at Stations 13/TT-27, WH, NT-3, and CB-03. All stations are located within the Wells G&H 38-acre wetland except for Station CB-03, the sample in the former cranberry bog. Station NT-3 is an area within potential future land use scenarios developed by the City of Woburn for the construction of a nature trail within the Wells G&H wetland. Station 13/TT-27 is located on the western side of the Wells G&H 38-acre wetland.
- The risk exceedances were due primarily to the presence of arsenic in sediment. For Stations 13/TT-27, WH, and CB-03, areas of significantly elevated arsenic concentrations were localized in nature. Benzo(a)pyrene was also a minor risk contributor at Stations 13/TT-27 and WH. The risk associated with benzo(a)pyrene and

the concentrations of benzo(a)pyrene present at these stations fall within the range of estimated risks and detected concentrations at the reference stations.

8.6.1.2 Sediment Cores

Sediment cores were evaluated for a potential future dredging scenario which assumed that workers would contact contaminated sediments up to 4 feet in depth during excavation/dredging for flood mitigation and control construction projects. Worker exposures evaluated included incidental ingestion of and direct dermal contact with sediments. Table 8-2 summarizes the potential dredging worker risks and hazards at each sediment core location. Figure 8-1 also shows the sediment core locations associated with future risks and hazards in excess of regulatory guidelines.

- For the future scenario, hazards above risk management guidelines were estimated at sediment core locations SC02, located in the HBHA wetland, and SC05, SC06, and SC08, located within the Wells G&H 38-acre wetland. The risk exceedances were due primarily to the presence of arsenic in sediment.

8.6.1.3 Soil

Recreational exposures evaluated included incidental ingestion of and direct dermal contact with floodplain soils. Recreational receptors (young children, teenagers, and/or adults) were selected for evaluation at individual stations after consideration of current and potential future land use (e.g., residential, park land, or commercial). In addition, residual soil contaminants within the former Mishawum Lake bed were evaluated for potential exposures to current and/or future day care children, groundskeepers, and construction workers. Table 8-3 summarizes the current and future soil risks and hazards for each receptor and station/area. Figure 8-2 shows the soil locations associated with future risks and hazards in excess of regulatory guidelines.

- For the future scenario, risks and hazards above risk management criteria were estimated for future day care children exposed to surface (i.e., SO-13, SO-14 and SO-16) and subsurface soils (i.e., SO-13, SO-11, SO-3, and SO-14) within the former Mishawum Lake bed area due primarily to arsenic.

- Non-carcinogenic hazards above risk management criteria were estimated for future construction workers exposed to subsurface soils (i.e., SO-13, SO-11, SO-3, and SO-14) within the former Mishawum Lake bed area due primarily to arsenic.

8.6.1.4 Groundwater

Specific industrial groundwater use evaluated included process water use (ingestion, dermal contact, and inhalation exposures) and the use of groundwater in a warm water car wash (inhalation exposures). Because groundwater throughout the study area is relatively shallow, future construction workers may also be exposed to groundwater contaminants during excavations down to the water table. Table 8-4 summarizes the future groundwater risks and hazards for each receptor. Figure 8-3 shows the monitoring well locations associated with future risks and hazards in excess of regulatory guidelines. Risks and hazards in excess of USEPA risk management criteria were estimated for groundwater used as process water, used in a warm water car wash, and for worker-related exposures to shallow groundwater.

- The primary risk contributor for process water use and for construction worker-related exposures is arsenic.
- Benzene, trichloroethene, and naphthalene were also identified as primary risk contributors for process water use and the use of groundwater in a warm water car wash.
- Additional minor risk contributors for process water and warm water car wash use include: 1,2-dichloroethane, chloroform, and methyl tert-butyl ether. Pentachlorophenol was also identified as a minor risk contributor for the process water exposure scenario.

8.6.1.5 Uncertainty

The following summarizes the major sources of uncertainty in the risk assessments:

- In cases where there is high degree of variability between the data points for a contaminant, an exposure point concentration (EPC) may be uncertain. For example, the sediment EPC for arsenic at sediment core location SC02 is uncertain due to one

elevated arsenic detect (1,600 mg/kg in the 0- to 1- foot depth interval) compared to the remainder of the data set. This uncertainty is also applicable to SO soils due to sampling location SO-13 (2,680 mg/kg in the 8-foot interval), sediments at Station 13/TT-27 due to sampling locations SD-13-01-FW and SD-13-02-FW (4,210 mg/kg and 2,480 mg/kg), sediments at Station WH due to sampling location SD-12-01-ME (3,230 mg/kg), and sediments at Station CB-03 due to sampling location CB-03-11 (1,410 mg/kg). This uncertainty may result in either an overestimate or underestimate of risk.

- Even though low-flow sampling techniques were used to collect Northern Study Area groundwater samples, a number of monitoring wells could not be stabilized prior to the collection of groundwater samples. These samples may have contained elevated levels of suspended particulate materials, resulting in an overestimate of the bioavailable contaminant levels in the samples. Risk estimates based on groundwater samples containing elevated levels of suspended solids may overestimate risk.
- Future air EPCs for the industrial and commercial groundwater use scenarios were generated from groundwater data through the use of volatilization and dispersion modeling. Parameter values used in these models were selected to represent reasonable maximum exposures that may occur in the future should groundwater be used as process water or for use in a warm water car wash. The risk associated with future groundwater use may be less than estimated should groundwater uses that result in a lower degree of worker exposures be considered (e.g., use of groundwater for cooling in a closed system).

8.6.1.6 Summary of Human Health Risks

As identified in the baseline human health risk assessments and supported by the management of EPA's Office of Site Remediation and Restoration, the following contaminants, media, and locations exceed risk management guidelines established for human exposures:

Current Scenario

- Arsenic in sediment at Stations WH and CB-03 in the Southern Study Area.

Future Scenario

- Arsenic in sediment at Stations 13/TT-27, WH, NT-3, and CB-03 in the Southern Study Area;
- Arsenic at sediment core locations SC02 in the Northern Study Area and SC05, SC06, and SC08 in the Southern Study Area;
- Arsenic in soil at locations SO-3, SO-11, SO-13, SO-14, and SO-16 in the Northern Study Area;
- Arsenic in groundwater at monitoring wells B7-01, B4-04, B7-02, B6-03, B5-02, and B8-04 in the Northern Study Area;
- Benzene in groundwater at monitoring wells B5-01, W5-06, W5-05, B7-03, B9-02, B9-01, and W5-03 in the Northern Study Area;
- Trichloroethene in groundwater at monitoring wells AE-03, W5-03, AE-02, AE-04, and AE-06 in the Northern Study Area; and
- Naphthalene in groundwater at monitoring well W5-05 in the Northern Study Area.

It should also be noted that the migration of arsenic-contaminated surface water from the HBHA in the Northern Study Area to depositional areas in the Southern Study Area (i.e., the Wells G&H 38-acre wetland and the former cranberry bog) contribute to the human health risks and hazards above risk management guidelines observed at sediment stations 13/TT-27, WH, NT-3, and CB-03 in the Southern Study Area.

8.6.2 Ecological Risks

The baseline ecological risk assessments used effects-based screening criteria to identify contaminants of potential concern (COPCs) in each medium. Receptor species were selected for exposure evaluation to represent various components of the food chain in the river/wetland ecosystem, and included: muskrat, green heron, mallard, short-tailed shrew, benthic

invertebrates, and several species of warm water fish. In addition, in the Northern Study Area, a piscivorous mammal, the river otter, was also evaluated.

The risks identified for each receptor were reviewed with consideration of the level of the risk to the population or community, the uncertainty associated with the analysis, and the amount and quality of the affected resource. The results were interpreted further within the context of the magnitude of the effect, the uncertainty of the estimates, and the ecological significance of the effect. Overall summaries of estimated risks are presented for each receptor species or community in Table 8-5.

Each endpoint has associated with it a magnitude of risk and a degree of uncertainty. The magnitude of risk incorporates both the degree to which the endpoint was exceeded and also the proportion of the habitat affected. Since the endpoints were population-based, a reasonable probability of risk was determined to be present only when a risk was present throughout the majority of the organism's habitat. The ecological significance related to each receptor/endpoint was evaluated in terms of factors defined by EPA. An evaluation of these factors is used to clarify if risks associated with contamination are present at levels that represent unacceptable ecological risk. Each of the six categories evaluated in Table 8-5, were used to support a conclusion about the ecological significance of each endpoint where risk was identified. The magnitude of the potential risk was further considered when evaluating the significance of each factor.

Based on the analysis of the seven selected indicators/endpoints, the only area of significant ecological risk is in the HBHA Pond, where the potential risk to aquatic receptors is due to benzene in the deeper water and the potential risk to the benthic invertebrate community is due to inorganics COPCs, especially arsenic. In addition, evidence suggests that there is high exposure to inorganic COPCs, especially arsenic, for semi-aquatic mammals, bottom feeding fish, and small forage fish in several other areas in the MSGRP RI Study Area. However, in general, the resulting level of ecological risk for these receptors is low. The magnitude of these risks and the uncertainty associated with the ecological effects for each receptor is discussed below.

8.6.2.1 Ecological Risks Due to Surface Water

Surface water screening indicated a possible risk to aquatic life from exposure to benzene and arsenic in the HBHA Pond. Exposure is mainly to aquatic invertebrates in the deep water at the sediment-water interface. Downgradient of HBHA Pond, the surface water concentrations of dissolved arsenic were below National Ambient Water Quality Criteria (NAWQC) and were well below those expected to cause effects on aquatic life, including invertebrates, and fish.

8.6.2.2 Ecological Risks Due to Sediment

The effects of sediment contaminants on sediment-dwelling benthic invertebrates was the subject of extensive analysis, including toxicity testing, invertebrate tissue analyses, and benthic invertebrate community studies. An evaluation of the benthic invertebrate measurement endpoints indicates that there were potential impacts from inorganic contaminants on invertebrate communities within the study area. Data were used to evaluate the relationship of sediment contaminant concentrations, benthic invertebrate toxicity testing results, and benthic community composition data.

- There is evidence of severe toxicity to benthic organisms at the HBHA Pond. Some evidence of invertebrate toxicity was also observed indicating potential effects from exposure to sediments at stations downstream of the HBHA Pond in the HBHA Wetland sediments and in reaches 1 and 2 of the Southern Study Area. The toxicity testing results were highly correlated to sediment arsenic concentrations, particularly when the effect of high iron concentrations was taken into account.
- Although severe impairment of communities was not observed in the Southern Study Area, a reduction in diversity and an increase in dominance of oligochaetes and chironomids was observed in stations with higher arsenic concentrations.
- Based on multivariate analysis of community composition, the strongest factors affecting the invertebrate community were the acid volatile sulfide (AVS) content of the sediment, the depth of the sampling location, the dissolved oxygen in the overlying water, and the habitat characteristics (flow) of the location from which the sample was collected. These factors are considered environmental variables that are not associated

with chemical contamination. When these environmental variables are segregated from the overall community composition effects, the results show a portion of the community structure is strongly correlated to the sediment arsenic:iron ratio. Stations with high arsenic concentrations, but with high iron as well, have lower toxicity due to the effect of iron to bind arsenic in less toxic forms. The availability and toxicity of arsenic in the HBHA Pond is unique due to the strongly reducing conditions in the water. The discharge of dissolved arsenic at the sediment-water interface, at concentrations well above NAWQC values, support the conclusions that the absence of invertebrates is related to contamination in the sediments of the pond.

- The levels of contaminants observed outside of the HBHA Pond correspond to detectable but small changes in community composition correlated to contaminant concentrations in the sediment, particularly with arsenic:iron ratios. The analysis indicates that the benthic community shows some shifts in community composition which is associated with the bioavailable fraction of arsenic in the sediment (represented by the arsenic:iron ratio). The community analyses also support the conclusions that the community structure at the two deep stations in the HBHA Pond are uniquely impaired and dissimilar to other study area and reference stations.

The summary of risk (Table 8-5) indicates a difference in the magnitude of the risk to benthic invertebrates between the HBHA Pond and the remainder of the combined study area. In the HBHA Pond, there is a high risk and confidence, based on several supporting lines of evidence, that there is severe toxicity and impairment of benthic communities. In the downgradient areas (HBHA Wetlands and the Southern Study Area), the evidence indicates a low magnitude of toxicity, although there was a high correlation of effects with distribution of site contaminants (primarily arsenic).

Since benthic invertebrates provide important functions in aquatic ecosystems, the impact on the benthic community in the HBHA Pond, with severe toxicity and impairment of benthic communities, represents a significant ecological effect. Due to the magnitude of the adverse effect on this receptor community, the impact on the benthic community in the HBHA Pond represents an unacceptable ecological risk.

8.6.2.3 Ecological Risk Due to Soil

Risks from exposure to soil-related contaminants were evaluated first by screening soil concentrations against soil screening benchmarks. As a second step, effects on terrestrial receptors exposed to soil contaminants through ingestion of biota exposed to soils was addressed in the food chain models using short-tailed shrew as the small mammal receptor.

8.6.2.4 Ecological Risks to Fish and Dietary Exposures

The potential effects of contaminant exposure on fish populations were evaluated through analysis of fish tissue COPC concentrations in both the Northern and Southern Study Areas. In addition, population studies were conducted in the Northern Study Area in order to document the fish community structure at two study area ponds (HBHA Pond and HBHA Wetland Pond No. 3) as compared to two reference ponds.

- The population data from the Northern Study Area indicated impairment of fisheries; however, the relative influence of poor quality habitat conditions could not be distinguished from impacts associated with toxicity from contaminants. The tissue data provided evidence of potential ecological effects in the Northern Study Area and negligible effects in the Southern Study Area; although population data are inconclusive about the role of toxicity in impairing fish populations in the Northern Study Area ponds. The risks to fish were possibly underestimated based on the inability to discern any impacts from the exposure to toxic substances from impacts associated with the limited and poor overall habitat.
- The risks to fish populations is located in the Northern Study Area ponds and associated with the high exposure to arsenic. The area of highest exposure and potential impacts is in the HBHA Pond and the HBHA Wetland Pond No. 3, which also represents an area of relatively low quality aquatic habitat. The value of the potential resource at risk is relatively high, as the affected receptors included populations of several species of bottom feeding and small foraging fish. The magnitude of the risk is low, with uncertainty (Table 8-5) related to the lack of ability to discern impacts associated with contamination from the population studies. Although this endpoint represents a potential impact of relatively high ecological significance, the measured magnitude of the risk is

low, and associated with uncertainty. Hence, the overall impact on fish populations is not considered an unacceptable ecological risk.

- Estimates of dietary exposures for wildlife were quantified for each of the selected receptor species. Dietary exposure models were used to estimate exposure of each receptor species to each of the COPCs identified in the screening of sediment, surface water, and soil data (as applicable) from the study areas. Based on the dietary modeling, there were negligible risks to green heron from exposure to COPCs in both of the study areas. In addition, there were negligible risks to river otter from exposure to COPCs through dietary exposure in the Northern Study Area. The majority of the diet for both green heron and river otter was based on consumption of fish. Since the concentrations of COPCs in fish tissue were generally lower in the Southern Study Area, risks to otter in these reaches would also have been negligible (Table 8-5).
- Food chain modeling based on site-specific data indicated negligible risk to mallard duck from exposure to COPCs in the Northern Study Area. For mallard, chromium, lead, and mercury posed low risk in the Southern Study Area, mainly within the Wells G&H 38-acre wetland, resulting from high sediment concentrations of these metals in Reaches 1 and 2. The likelihood that high concentrations of sediment metals in limited areas of the 38-acre wetland will have serious population effects on a species with wide foraging ranges, like mallards, is low. Although habitat of the 38-acre wetland is considered to be of relatively high quality and local ecological significance, the low probability of impacts on the receptors result in low ecological significance of the effects on waterfowl (Table 8-5). Hence, the impact on the mallard population is not considered an unacceptable ecological risk.
- Based on the muskrat models, there is potential risk to muskrat from ingestion of arsenic. These risks have been evaluated in the context of the limitations of the data and the models. Within this context the risk to muskrat exceeds levels potentially associated with harm (growth or reproduction), but the uncertainty associated with these estimates are high. Muskrat have been observed in the study areas, but this fact alone does not conclusively prove the level of the effect on the population, as these individuals may have inhabited only the less contaminated areas, or may have represented recruitment from adjacent habitats. The results of the risk assessment identified potential effects

(i.e., chronic impacts) on reproduction or growth. The assessment population was operationally defined to be the population within the study area. The population is regulated by births and deaths (which may be affected by study area conditions) as well as immigration and emigration of individuals from adjacent areas. Severe effects on a receptor could remove individuals from the assessment population, or decrease reproductive rates and cause the study area to serve as a sink for the regional population. In this case, lower reproduction rates within the study area might be compensated by an increase in immigration. The resulting subtle impacts on population density within an urban study area would not likely be detected from field surveys.

The relatively low magnitude of the risk estimates (HQ values less than 10) and the high uncertainty associated with the models leads to a conclusion of low probability of significant population effects on muskrat in the study areas. Based on the data collected, the risk assessment does not provide sufficient evidence to conclude that arsenic contamination in the study areas is causing an adverse effect on muskrat populations that is of sufficient magnitude, severity, and extent that the population will not be maintained in an acceptable state. Hence, the impact on the muskrat population is not considered an unacceptable ecological risk.

- Arsenic was identified as posing a potential effect on shrew in both the Northern and Southern Study Areas. The relatively low magnitude of the risk estimates and the high uncertainty associated with the models leads to a conclusion of low probability of significant population effects on short-tailed shrew and other small terrestrial mammals in the study area. The available habitat for small terrestrial mammals such as short-tailed shrew is limited to the borders of the wetland. Although the habitat for small mammals may be locally important, the magnitude of the potential effects is low (with high uncertainty), leading to a conclusion of no significant ecological effects related to contaminant exposures to small mammal populations (Table 8-5). Hence, the impact on the shrew populations is not considered an unacceptable ecological risk.

8.6.2.5 Ecological Risk Conclusions

Based upon the evaluation conducted under this Baseline Ecological Risk Assessment Summary for the combined study areas, and supported by the management of the EPA's Office

of Site Remediation and Restoration, significant ecological risks are present in the HBHA Pond within the Reach 0 of the Northern Study Area immediately downstream of the current Industriplex Superfund Site boundaries. These significant risks were primarily associated with metals contamination, particularly arsenic, in the sediments and their toxicological effects on the benthic invertebrate community.

Risks to aquatic organisms are also associated with high observed concentrations of benzene and dissolved arsenic in the deep water of the HBHA Pond. Dissolved arsenic concentrations were measured significantly above National Ambient Water Quality Criteria values for aquatic life. These risks are consistent with the observed impairment of benthic invertebrates in the deep water of the HBHA Pond. These significant risks are considered unacceptable ecological risks to the HBHA Pond.

Risks to receptors downgradient of HBHA Pond are low (Figure 8-4). These include low risks to benthic invertebrates and herbivorous mammals, associated with high concentrations of sediment arsenic. These low risks are not considered unacceptable ecological risks to ecological communities in the HBHA Wetlands, Wells G&H 38-acre wetland, and Former Cranberry Bog.

8.7 MSGRP RI Conclusions

Chemicals have been detected in some areas of the MSGRP RI Study Area that have been shown to present human health risk and hazards above EPA risk management guidelines and unacceptable ecological risks. At a minimum, cleanup alternatives should be developed in the Feasibility Study to address the areas and major risk contributors summarized in the following table:

HUMAN HEALTH RISK			
RISK AREA	SCENARIO/ RECEPTOR	IMPACTED MEDIA	MAJOR CONTAMINANT CONTRIBUTING TO RISK
Industri-plex Site (Reach 0)	Future Construction Worker	Groundwater	(NC) - Arsenic
Industri-plex Site / HBHA Pond Area (Reach 0)	Future Industrial Worker	Groundwater, Indoor air	(NC) - Benzene, naphthalene, arsenic (C)- Trichloroethene
Former Mishawum Lake & South of Cabot Road Area (Reach 0)	Future Industrial Worker	Groundwater, Indoor air	(C)- Trichloroethene
Industri-plex Site / HBHA Pond Area (Reach 0)	Future Car Wash Worker	Indoor air	(C)- Trichloroethene (NC) - Benzene, naphthalene
Former Mishawum Lake & South of Cabot Road Area (Reach 0)	Future Car Wash Worker	Indoor air	(C)- Trichloroethene
Wells G&H Wetland (Reach 1); and Former Cranberry Bog (upper Reach 2)	Current/ Future Recreational Exposure	Sediment	(C) – Arsenic (NC) – Arsenic
HBHA (Reach 0); and Wells G&H Wetland (Reach 1)	Future Dredger/ Construction Worker	Sediment	(NC) – Arsenic
Former Mishawum Lake Area (Reach 0)	Future Day Care Child (surface soil)	Soil	(C) - Arsenic
	Future Day Care Child (subsurface soil)	Soil	(C) – Arsenic
	Future Const. Worker (subsurface soil)	Soil	(NC) - Arsenic
ECOLOGICAL RISK			
HBHA Pond	Benthic Invertebrate Communities	Sediment , Deep surface water	Arsenic and Benzene

(NC) – Non-carcinogenic Hazard

(C) – Carcinogenic Risk

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APPENDIX 1
BACKGROUND INFORMATION

(Intentionally Omitted - Reserved for Future Use)